NON-MOTORIZED VEHICLE CHARACTERISTICS AND ITS EFFECT ON MIXED TRAFFIC

A THESIS SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY

In

CIVIL ENGINEERING

[Specialization: Transportation Engineering]

By

Siddharth Purohit

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Department of Civil Engineering

National Institute of Technology, Rourkela

Odisha – 769008

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Under the supervision of

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Rourkela (India)

CERTIFICATE

This is to certify that the thesis entitled, **"Non-motorized vehicle characteristics and its effect on mixed traffic"** submitted by **Mr. Siddharth Purohit** in partial fulfillment of the requirements for the award of Master of Technology in Civil Engineering with "Transportation Engineering" Specialization during session 2011-2012 in the Department of Civil Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

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Odisha, India

ACKNOWLEDGEMENT

First and foremost I offer my sincere gratitude and respect to my project supervisor, **Dr. Ujjal Chattaraj,** Department of Civil Engineering, for his invaluable guidance and suggestions to me during my study. I consider myself extremely fortunate to have had the opportunity of associating myself with him for one year. This thesis was made possible by his patience and persistence.

After the completion of this thesis, I experience the feeling of achievement and satisfaction. Looking into the past I realize how impossible it was for me to succeed on my own. I wish to express my deep gratitude to all those who extended their helping hands towards me in various ways during my short tenure at NIT Rourkela.

I express my special thanks to **Mr. S. S. Mohapatra** for his help during the collection of data for the project. I also express my thanks to the staff members of Department of civil Engineering, NIT Rourkela for providing me the necessary facilities that is required to conduct the project and complete my thesis.

DATE: **SIDDHARTH PUROHIT**

ABSTRACT

In countries like India we generally can find a mixed traffic i.e. a traffic flow constituting of all type of vehicles like cycle, rickshaw, car, bus etc. In Indian cities the share of non-motorized transport (NMT) at peak hours too high. Every public transport mode of transport involves access trips by NMT at each end. Thus, non-motorized mode of traffic plays a very important role in meeting travel demand in countries like India.

To design a traffic facility it is necessary to understand the behavior of traffic stream. Understanding the behavior of a traffic stream with mixed traffic in quite complex. In this thesis an attempt to study the non-motorized vehicle characteristics and effect on mixed traffic is made.

This project work is divided into two parts. First part is the experimental part and the latter is the analytical part. In experimental part a study of fundamental diagram of data obtained from various roads of Rourkela city. It was seen that with increase in NMV % the flow versus density graph is adversely affected. Density decreases at a particular flow rate when NMV % increases. Along with this a study on pattern of lateral occupancy of NMVs and MVs was done with respect to various percentages of NMV and total density. It was seen that as the percentage of NMV increases the both NMV and MV are well distributed all along the road stretch, with a higher concentration in the right hand side of the road, blocking the flow from the opposite direction. In India it is left hand side drive, so it may lead to side way collision while over taking. Also sometime this may end with a traffic jam condition. In the experimental part a study on variation of speed with respect to various parameters was done. It was seen that speed decreases with increase in number of PCUs in the same strip, speed decreases with increase in number of PCUs in the adjacent strips and speed increase when distance from the road edge increases.

An attempt has been made to propose a model to simulate the speed of an NMV from the data obtained from experimental results. Fuzzy logic was used as a tool for linguistic classification of the premise variable in this model. As far as the simulation results are concerned it was seen that speed value obtained experimentally and obtained from the model are almost same. It was studied that all the three parameters have a significant impact on the speed of a non-motorized vehicle in a mixed traffic.

Key words: NMV, MV, PCU, fuzzy logic, lateral occupancy, mixed traffic.

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NOMENCLATURE

Description	**Symbol or short form**
Non-motorized transport	NMT
Non-motorized vehicle	NMV
Motorized vehicle	MV
speed	u
Flow	q
Density	k
Passenger car unit	PCU
Member ship value	μ
Fuzzy interference system	F.I.S
Number of PCUs in same strip	s_z
Number of PCUs in both adjacent strips	a_z
Distance of test vehicle from road edge	d_z
Consequence variable (speed in general)	S_r
Consequence speed value	S_1, S_2…..S_{27}
Weight of a membership subset	$w_{r,k}$

Chapter 1

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1. Introduction

In countries like India we generally can find a mixed traffic i.e. a traffic flow constituting of all type of vehicles like cycle, rickshaw, car, bus etc. In Indian cities the share of non-motorized transport (NMT) at peak hours is almost more than 50 per cent. This figure is even higher in medium- and small-sized cities. Different cities have different patterns of NMT use. Every public transport mode of transport involves access trips by NMT at each end. Thus, non-motorized mode of traffic plays a very important role in meeting travel demand in countries like India.

The flow of mixed or heterogeneous traffic is quite complicated. This mixed flow of vehicles leads to many problems like conflicts at intersections when number of non-motorized vehicle increases, when number of non-motorized vehicles increases it affects the speed and flow of other vehicles. It significantly lowers or reduces the capacity also leads to various safety problems. So there should be a separate track for flow of non-motorized traffic as used in various developed counties like USA, in countries like India this practically not possible. So in that case a proper study of non-motorized vehicle characteristics should be done along with study of how these NMV affects the mixed traffic.

As per World Bank survey (1990) about 53 % of poor people are there in Asian countries. These people depend on non-motorized mode of traffic for entire trip (for example, commuting, shopping). The demand for bicycles and rickshaws is therefore considerable at present and is likely to continue to be so. Hence study of both NMVs movement and it effect on motorized mode are taken into account in the project.

1.1 Basic parameter of traffic flow

1.1.1 Speed

In traffic engineering language speed is defined as the distance travelled by a vehicle over a certain period of time. It’s not impossible to calculate the speed of every individual vehicle. Due to this the average speed is taken into consideration. In two ways Average speed can be calculated. They are time mean speed and space mean speed.

Time mean speed is defined as the average of speed of vehicles crossing a particular section.

Space mean speed is defined as the ratio of distance (length) of particular section and the average time of vehicles crossing that particular section.

1.1.2 Flow

It is defined as the ratio of number of vehicles crossing a particular section and the time taken by the vehicle to cross that particular section.

Units: vehicles/time

1.1.3 Density

After a particular time the number of vehicles which occupy the particular region is defined as density. The density is generally averaged over certain duration of time.

Units: vehicles/distance.

The above mentioned flow parameters are related to a basic equation

$$q = u * K$$

1.2 Fundamental diagrams of traffic flow

There are three curves which show the relation in between the density vs speed, speed vs flow, flow vs density. These are explained as follows.

1.2.1 Speed-density relation

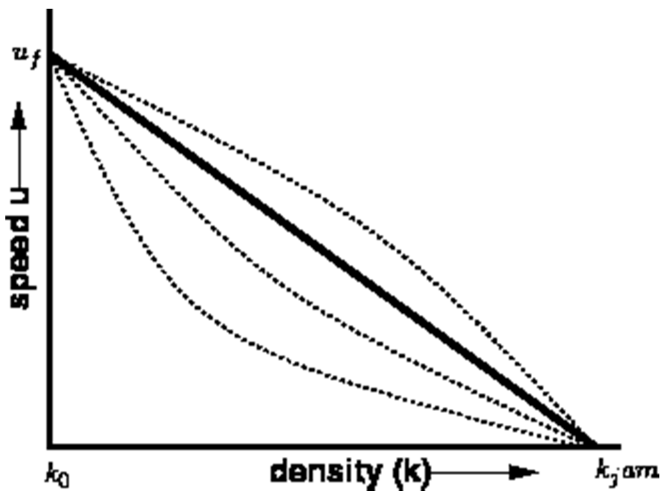

Fig 1.1 Speed-density diagram*

From the diagram it can be seen that

- Speed will be maximum (free flow speed) when the density is zero.
- Speed is zero then density is maximum.
- Variation of speed with the density is linear in shape
- At jam density speed of vehicles is clearly zero.
- Non-linear relationships can be obtained from the figure which is represented separately in dotted lines.

1.2.2 Speed-flow relation

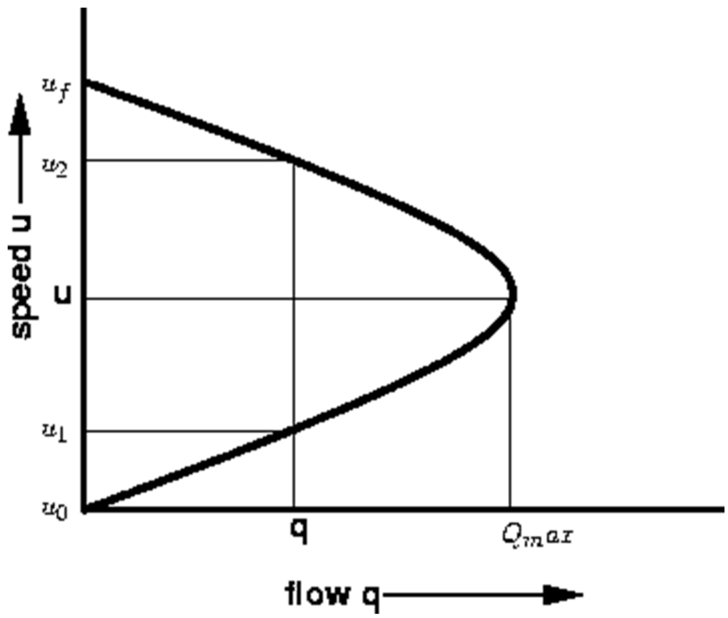

Fig 1.2 Speed-flow diagram*

The relation in between speed and flow can be explained as follows

- Flow is considered to be zero when there are no vehicles or there are so many vehicles such as it not possible to move.
- If speed is either zero or free flow speed than flow will be maximum.
- At speed u the maximum flow q_{max} occurs. For a given flow there can be two different speeds.

1.2.3 Flow-density relation

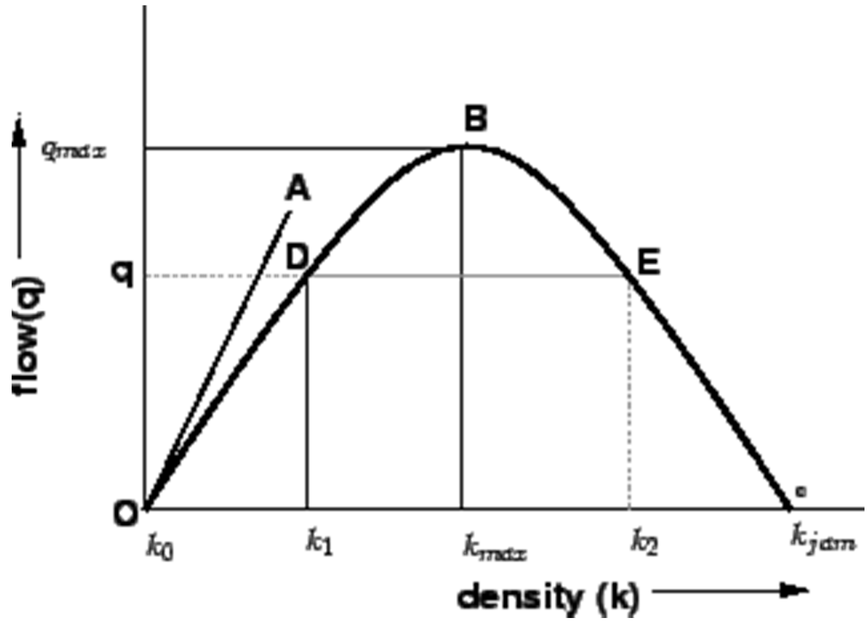

Fig 1.3 Flow density curve*

If time and location varies then flow and density also changes. The relation in between the flow and density are mentioned below.

- If no vehicles are there on the road then the density is zero and obviously flow is zero.
- When the number of vehicles on the road stretch increases then density and flow will increase.
- Jam density is the point where number of vehicles on the road stretch is maximum. The flow is zero at the position of jam density because vehicles are not moving.
- When flow is at its maximum the point on density scale is known as maximum density k_{max}.
- Relation between flow and density is parabolic as shown in figure.
- Slope of the tangent to the curve at any point gives the speed at that point of time.

From the figure point O refers as zero density and zero flow. At point B maximum flow occurs and the corresponding density is known as k_{max}. Flow is zero at point C and the density is known as jam density i.e. k_{jam}. The slope of tangent OA gives the speed with which a vehicle passes on the road stretch. For the same flow there can be two different densities (in the figure at point D and E respectively). Slope of the line OD gives the speed at density k_1.Similarly the speed at density k_2 can be found out. It is very clear that the speed at density k_1 is higher due to less number of vehicles on the road stretch.

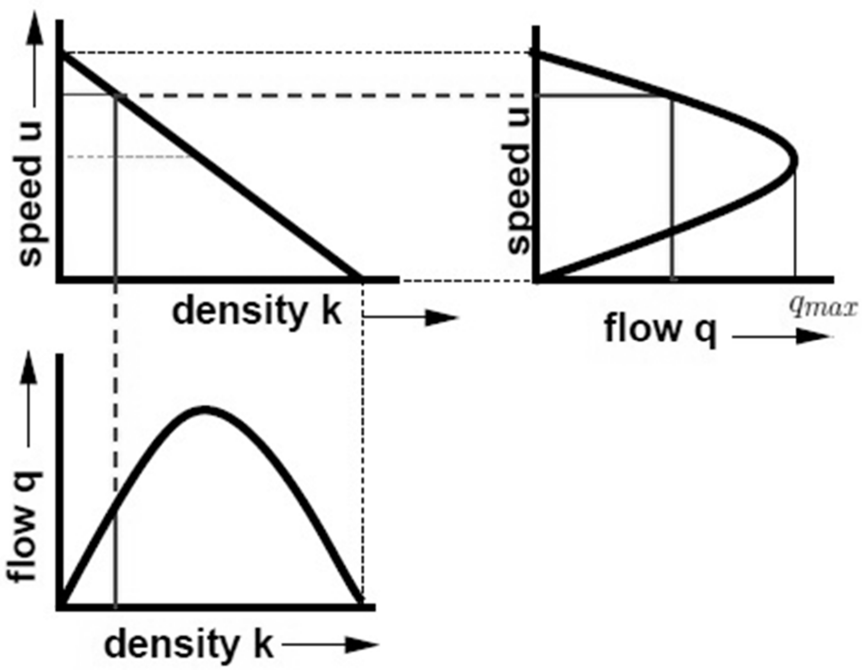

Fig 1.4 Fundamental diagram of traffic flow*

*[Fig 1.1, 1.2, .13, 1.4 is adapted from http://en.wikibooks.org/wiki/fundamentals of Transportation/traffic flow]

1.3 Non-motorized vehicles (NMV)

Before moving into the project it’s very important to know what are an NMV and MV. The term 'Non-Motorized Vehicles' (NMVs) is refereed to different types of pedal powered vehicles used in the Indian subcontinent. These include different shapes and sizes of bicycles and tricycles. Tricycles are used to carry goods and passengers; these are commonly called as cycle rickshaws.

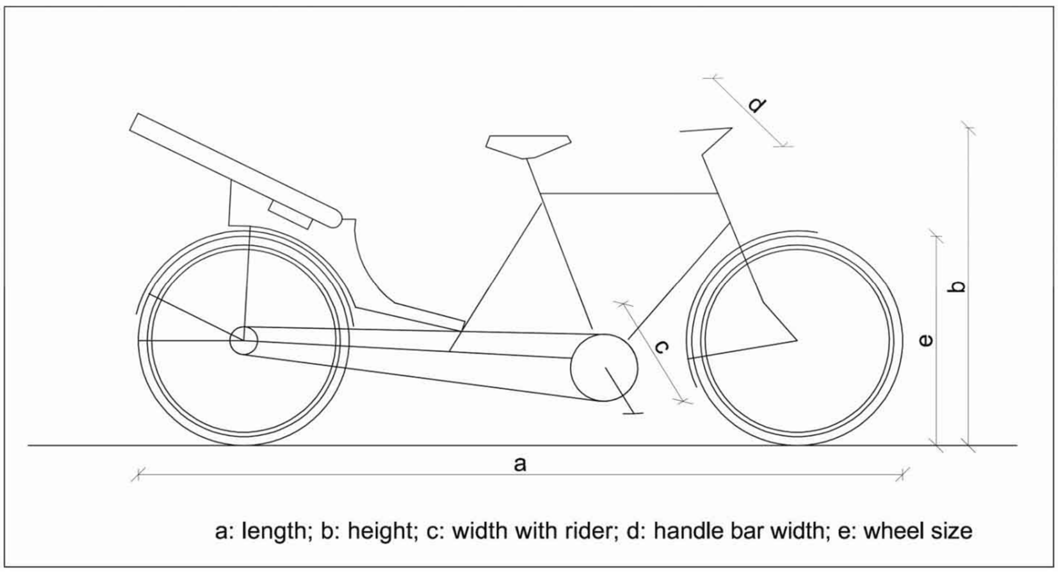

Fig 1.5 Passenger Rickshaws*

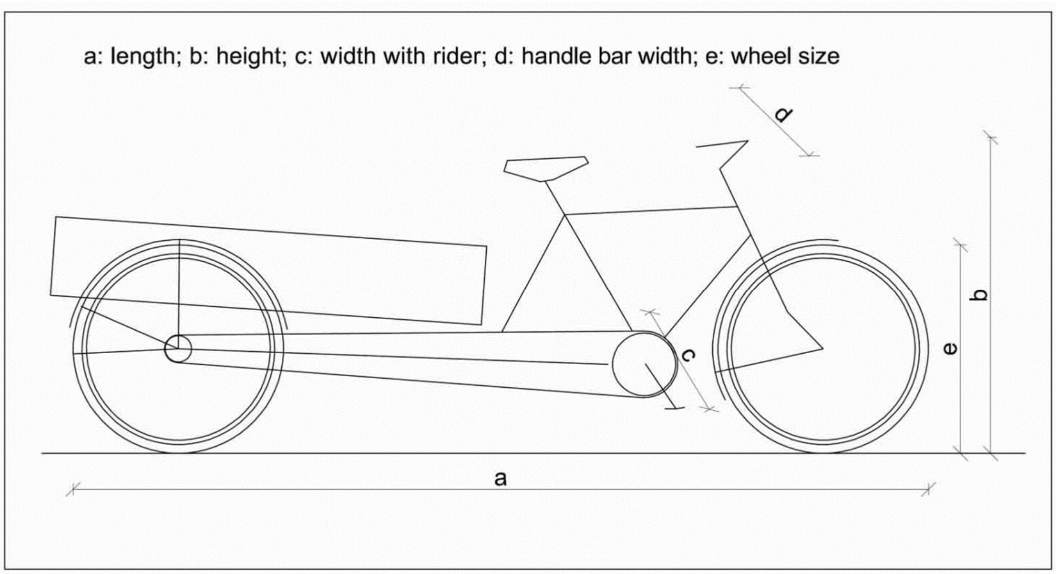

Fig 1.6 Goods rickshaw*

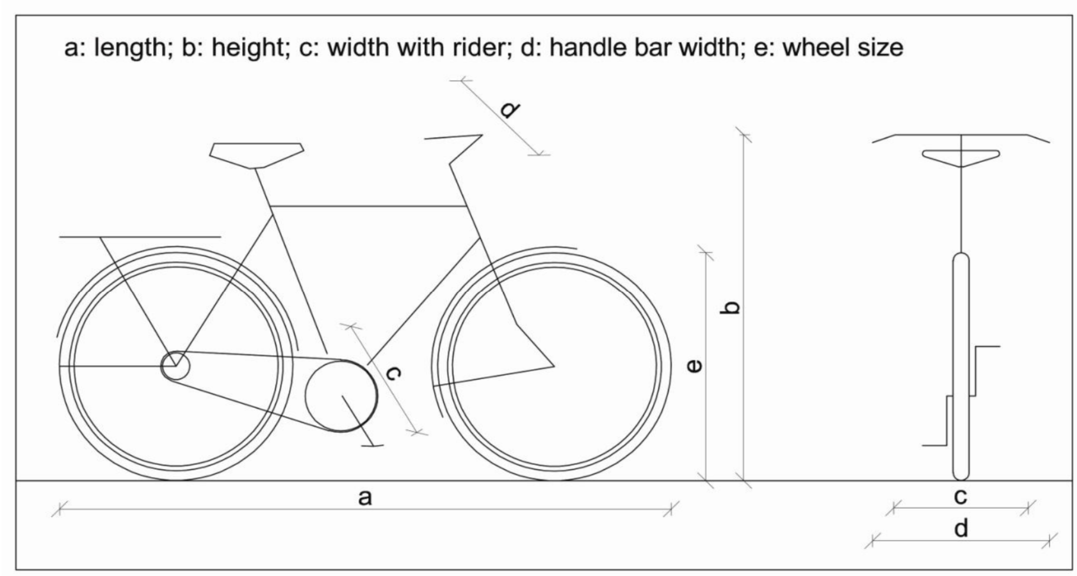

Fig 1.7 Vehicle dimensions for pedal cycle*

The table below shows the various dimensions of NMVs commonly used

*[Fig 1.5, 1.6, 1.7 are adopted from Bicycle Infrastructure Design Manual for Indian Sub-continent]

Table 1.1 various dimensions of NMVs

Type of NMV	a Length (mm)	b Height (mm)	c Width with rider (mm)	d Handle bar width (mm)
Pedal cycle	1800-1950	990-1200	750	500-600
Passenger Rickshaw	2000-2200	990-1200	900-1000	500-600
goods rickshaw	2200-2400	990-1200	1000-1220	500-600

1.4 Category of vehicles to be of concerned in the project

1. Non-motorized vehicles
   - I. Pedal cycles (NMV).
   - II. Pedal rickshaws.
2. Motorized vehicles (MV)
   - I. Motor cycle or bike.
   - II. Auto rickshaw.
   - III. Car
   - IV. Bus/truck.

Whenever terms like NMV and MV is there in this thesis, it refers to non-motorized vehicle and motorized vehicles respectively.

1.5 Passenger car unit (PCU)

In countries like India various class of vehicle like bus, trucks, cars, and cycle's etc. use same road way facilities without segregation. This kind of traffic is known as heterogeneous traffic or a mixed traffic. All vehicles have their own properties so it's difficult for a mixed traffic as compare to a homogeneous traffic. Thus here comes the use of a term called passenger car equivalence factor. This is used to convert all vehicles to a single unit called PCU.

PCU is defined as measure of the relative space requirement of a vehicle class compared to that of passenger car under a specified set of roadway, traffic and other conditions. PCU can also be treated as ratio of capacity of the road section with passenger cars only to the capacity of same section with a particular class of vehicle only. PCU of a passenger car is taken as 1. So PCU of other vehicles can be found out with relative to a passenger car.

In this case it's a mixed traffic condition hence every vehicle i.e. an NMV or a MV, all should be converted to a single unit for comparison.

So for PCU value IRC: 73-1980 was followed. The following table gives the equivalency factor suggested by IRC.

Table 1.2 equivalency factor suggested by IRC.

Sl no	Vehicle class	Equivalency factor
1	Passenger car, tempo, auto rickshaw, tractor.	1.0
2	Bus, truck, tractor-trailer units.	3.0
3	Cycle rickshaw	1.5
4	Motor cycle, scooter, pedal cycle.	0.5

Chapter 2

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2. Literature review

As the project is based on Non-motorized vehicle properties and its effect on mixed traffic hence a literature survey was done in the field of work done on non-motorized vehicles. The importance of non-motorized vehicle traffic is already presented in chapter 1. There are so many works done in this field. However some of them are presented below;

Pan and Kerali (2007) conducted a research on the effects of non-motorized traffic flow on motorized vehicle speeds on the basis of field observations of vehicle speeds on Chinese roads. They observed linear relationship between motorized vehicle speeds and non-motorized traffic flow under a range of motorized traffic flow volumes. They developed a general congested speed model for predicting vehicle speeds under various road characteristics and traffic flow volumes, using the relationships of non-motorized flow effects obtained in their study along with free speed and speed-flow relationships investigated in other studies.

Rahman and Nakamura (2005) introduced a method for estimating passenger car equivalents (PCE) for non-motorized vehicle at mid-block sections of urban arterials based on speed reduction of passenger cars in the mixed flow due to the presence of non-motorized vehicles. The objective was to establish the relationships between PCE values and proportion of non-motorized vehicles and flow level. Average speed of passenger cars in basic flow and mixed flow were calculated from the observed data collected from two mid-block sections of Dhaka, Bangladesh. The results from the study say that presence of rickshaws had a significant impact on the average speed of passenger cars in the mixed flow. PCE value of rickshaws increases with the increases of flow rate and proportion of rickshaws.

Oketch (2003) developed a special model to investigate the effects of various non-conventional vehicles on stream performance including lane capacity and saturation flows. This paper say that for such heterogeneous streams had reduced link capacities and lane saturation flows in comparison to homogenous flows with private cars only, although the trends were not always consistent. In this study, the model was used to study speed flow relationships and trends in capacity and saturation flows for traffic streams containing non-standard vehicles. It was found that the presence of some of these vehicles resulted in a highly scattered volume, speed density plots, which hardly corresponded with the known fundamental traffic relationships. He concluded that such heterogeneous streams have peculiar flows that may not conform fully to the basic traffic theories. In addition, heterogeneous flows are generally associated with higher number of lateral movements as the faster vehicles try to overtake the slower ones.

Rahman and et al (2004) conducted a study on effect of rickshaw and auto rickshaw on the capacity of urban signalized intersection. For capacity analysis, to convert the mixed traffic flow into basic traffic flow passenger car equivalents plays an important role. This study also aimed at developing an estimation method of passenger car equivalent of rickshaws and auto rickshaws at signalized intersections by a macroscopic approach. They used data obtained from four signalized intersection of Dhaka, Bangladesh. They found that estimated PCE value of rickshaws and auto rickshaws of the study were different from the assumed PCE values that were used by traffic engineers of Bangladesh. They found a linear relationship between PCE value and proportion of rickshaws and auto-rickshaws. The presence of rickshaws in the mixed flow conditions affect the capacity of signalized intersections more adversely at a lower proportion than that of at a higher proportion of rickshaws.

Rahman and et al (2003) made a study on the effect of non-motorized vehicles on urban road traffic characteristics. They collected data from four mid-block sections of Dhaka, Bangladesh. They use time code reader software for extraction of data. They concluded that non-motorized vehicles have adverse effect on fundamental traffic parameters. A straight line relationship was found between passing/overtaking and total volume due to data range covered was uncongested region. They found an unclear pattern for passing/overtaking and proportions of non-motorized vehicles.

Xiao and et al (2011) made a study for calculating straight lane capacity under mixed traffic conditions, in China. The First Discharge Headway (FDH) was applied as a novel to improve Stop Line Method model, and the influencing factors of FDH were analyzed. To calibrate the FDH probability distribution, investigation data of four intersections in Beijing were used. With this model, the paper analyzes conflicting pedestrian and non-motor volumes' impact on capacity under mixed traffic conditions. The results show that FDH is only related to vehicle type and external disturbance factors and there is no mutual influence between each other. The traffic capacity decreases exponentially with the increase of conflict frequency between pedestrians, non-motors and motorized vehicles.

Dianhai and et al (2007) made a study on bicycle conversion factor calibration at two-phase intersections in mixed traffic flows. Their study is based on data collected from eight locations from various cities in china. They proposed model to calculate the through bicycle traffic and left-turn bicycle traffic conversion factors in intersections where bicycles and motor vehicles share the same road. The results indicate that the through bicycle conversion factor is 0.28 and the left-turn bicycle conversion factor is 0.33. This conclusion differs from the values used in China.

2.1 Motivation

It has been seen that study on non-motorized vehicles is done mainly in foreign countries. Less study on non-motorized vehicles and mixed traffic has been done in Indian context. Also it has been seen mainly the study are based on capacity estimation, PCU estimation and level of service estimation for non-motorized vehicles. No study has been done for pattern of lateral occupancy of the vehicles on Indian roads although study of passing and over taking has been done which is related to lateral occupancy. There are models for mixed traffic under influence of non-motorized traffic but there are a few models on non-motorized traffic movement in a mixed traffic. So under these circumstances some objectives have been defined for this project, which are presented in section 2.2.

2.2 Scope and objectives of the project

The proposed research work aims at analysing the characteristics of the non-motorised traffic flow and its effect on the motorised mode of traffic.

The entire work is divided into two parts

1. Experimental part.
2. Analytical part.

2.2.1 Experimental part

1. To study the variation in speed of NMV with respect to

    - Number of PCUs in the same strip.
    - Number of PCUs in the adjacent strip.
    - Distance of the test vehicle from the road edge.

2. To study of fundamental diagram of the traffic flow from the data obtained from various locations.

3. To study the effect of density and fraction of NMV on lateral occupancy of

    - Non-motorized vehicles.
    - Motorized vehicles.

.

2.2.2 Analytical part

Development of a model (computer simulation) for the speed variation of NMVs with respect to

- Number of PCUs in the same strip.
- Number of PCUs in the alternate strip.
- Distance of the test vehicle from the road edge.

Chapter 3

Empirical observations

As per the objectives described in chapter 2 there are two parts in the project

- Experimental part.
- Analytical part (proposed model).

This chapter describes the experimental part of the project. The analytical part is presented in chapter 3 (model structure) and chapter 5 (model simulation, calibration and validation).

This chapter consists of three parts i.e. data collection, data extraction and results for experimental observation.

3.1 Data collection

Data collection refers to the collection of video coverage from various locations. The entire project is about the data collected for various locations of Rourkela city. All in all five locations were selected each with different roadway conditions and different traffic compositions. The five locations on which the survey work was done are as follows;

1. Road near Rourkela main market, Rourkela.
2. Road near Aambagan market, Rourkela.
3. Road near Birsa chowk, Rourkela.
4. Road near konark cinema hall, Rourkela.
5. Road towards sector 2 from NIT Rourkela.

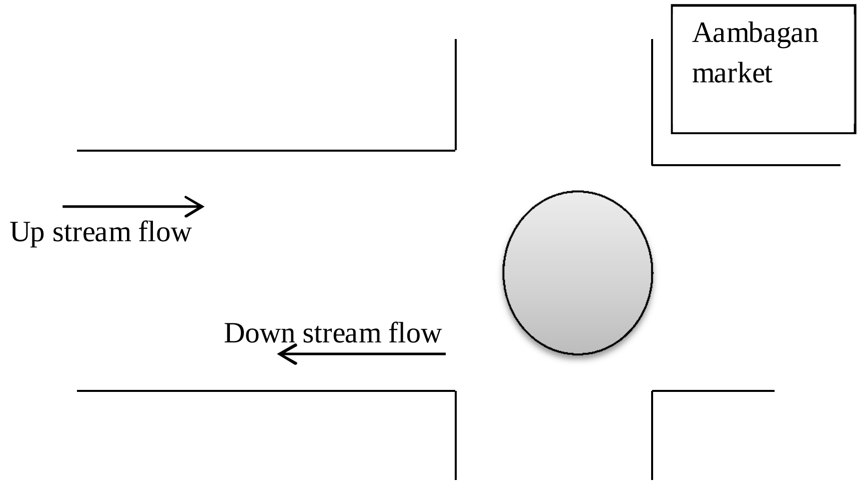


Fig 3.1 Road near Aambagan

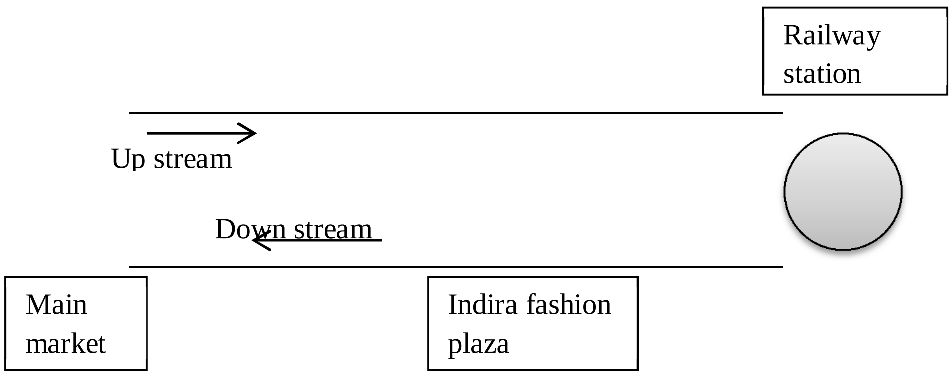


Fig 3.2 Road near Rourkela main market

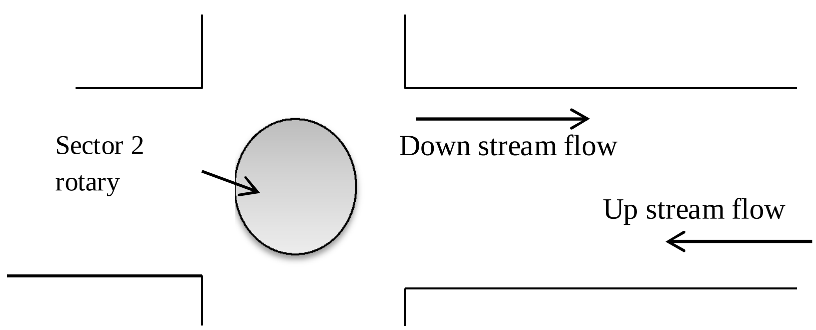


Fig 3.3 Road towards sector 2 from NIT Rourkela

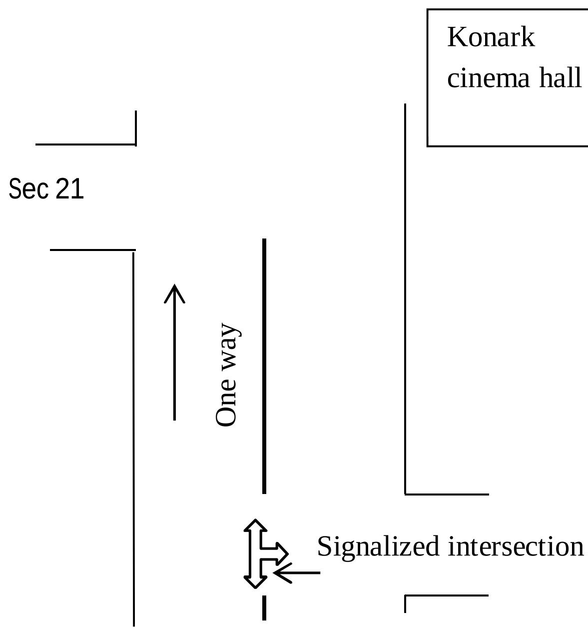
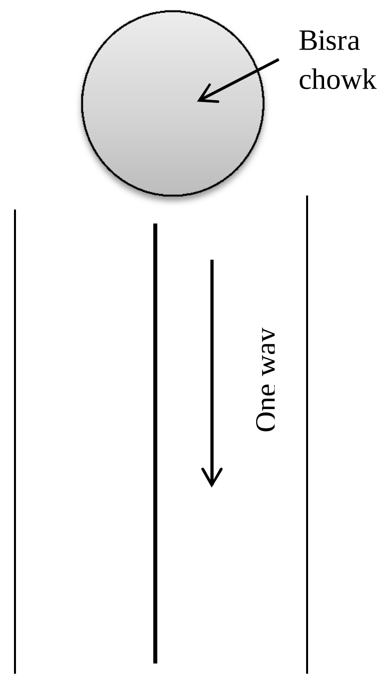


Fig 3.4 Road near konark cinema hall



3.5 Fig Road near birsa

A table showing width, length of various sections along with their time of data collection is presented below.

Table 3.1 Dimensions of various sections and timing of data collection.

Sl no	Location	Width of section (in m)	Length of section (in m)	Time of data collection	Date
1	Road towards sector 2 from NIT Rourkela.	7	5	9:15 am to 9:45 am	14.10.2011
2	Road near konark cinema hall	7.5	5	10:00 am to 10:30 am	14.10.2011
3	Road near Aambagan market	9	5	9:15am to 9:45 am	15.10.2011
4	Road near Rourkela main market	7	5	5:00 pm to 5:30 pm	15.10.2011
5	Road near Birsa chowk	10	7	9:15am to 9:45 am	16.10.2011

All the data were collected with a video camera for 30 minutes interval. A section on each road was selected which has sufficient number of non-motorized traffic. A 5m long section was selected and using some marking tools the four corners of the area has to be marked. And the video of the section was taken. All the data was recorded by using a video camera and later decoded in the computer by playing the video with the help of KM player. A cellophane paper was pasted of the computer screen. And the four corners were marked and joined with help of a white board marker. This was done because although the actual shape of the section in rectangular but when captured in a camera its shape gets deformed (it is shown the figures below). Then the data was decoded at per second rate or per frame rate (25 frames = 1 sec) as per the requirement. The data decoding or data extraction is presented in the section 3.2.

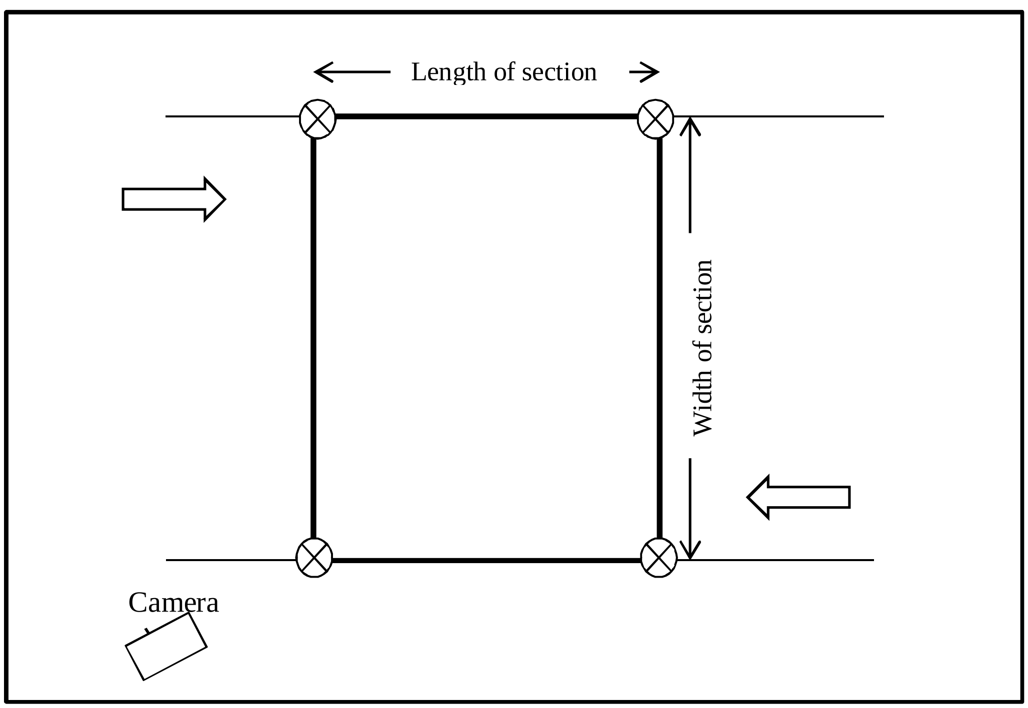


Fig 3.6 Schematic diagram showing the road cross section

Fig 3.7 Snap shot of data collected at road near Aambagan

3.2 Data extraction

Data extraction or data decoding refers to the experimental part of the project. As per the objectives defined in chapter 2, the experimental part comprises of the following;

1. To study the variation in speed of NMV with respect to
   - Number of PCUs in the same strip.
   - Number of PCUs in the alternate strip.
   - Distance of the test vehicle from the road edge.
2. To study of fundamental diagram of the traffic flow from the data obtained from various locations.

3. To study the effect of density and fraction of NMV on lateral occupancy of

   - Non-motorised vehicles.
   - Motorised vehicles.

3.2.1 Study of fundamental diagram of the traffic flow.

Fundamental diagram means the diagrammatic representation of the relationship between the various traffic parameters i.e. the relation between speed, flow and density. Definitions along with supposed fundamental diagram of speed, density and flow are already given in chapter 1.

For this study data was collected for four locations namely;

1. Road near Rourkela main market, Rourkela.
2. Road near Aambagan market, Rourkela.
3. Road near Birsa chowk, Rourkela.
4. Road near konark cinema hall, Rourkela.

If the data obtained from a 2 way road, data decoding was done for both way separately i.e. for upward flow or downward flow. This upward and down ward flow is already described in section 3.1 of this thesis.

Procedure followed

Here the collected video was played in KM player. A cellophane paper was pasted on the computer screen. All 4 corners were marked on computer screen and joined. For every 1 min interval the flow of vehicles i.e. the number of vehicles of each category passing the line in both directions was noted. Also for every 10 sec interval the density within the subjected region was determined for both motorized and non-motorized vehicles. Speed was calculated with relation u=q / K. And finally various fundamental diagrams for various locations were plotted. The results for this are presented in section 3.3.1.

3.2.2 Study of lateral occupancy

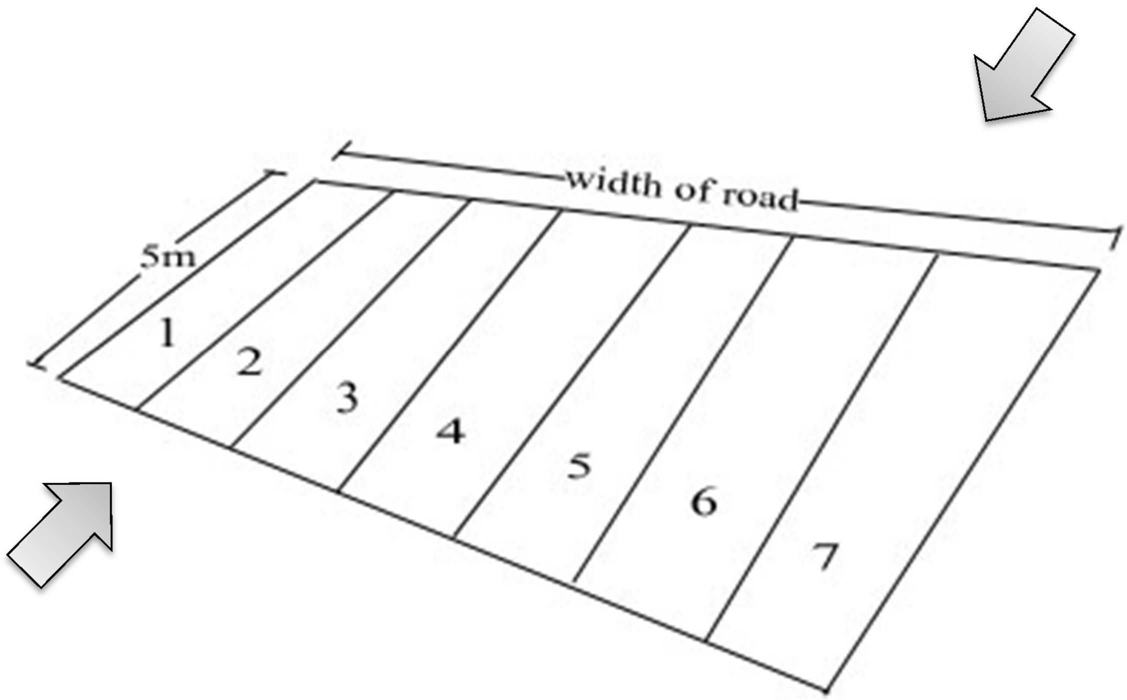


Fig 3.8 Road section for study of lateral occupancy

In this study the aim was to see how the NMV and MV vary laterally on a particular section of road when percentage of NMV and density of all vehicles changes.

For this study data was collected for four locations namely;

1. Road near Rourkela main market, Rourkela
2. Road near Aambagan market, Rourkela.
3. Road near Konark cinema hall, Rourkela.

All 4 corners were marked and joined. The area was divided into 7 equal strips. Width of one strip depends on width of the road. At every 10 seconds interval for each strip, number of vehicles of each category of vehicles was noted down. As per their PCU equivalent vehicles were converted to NMV and MV. Relative of total NMV and MV in each strip was found out. Graph between relative lateral occupancy and strip number was plotted for NMV, MV, and total traffic. Also the effect of density and percentage of NMV on lateral occupancy was studied. All these results are shown in section 3.3.2. Similar concept for space distribution was earlier used in Chattaraj and et al (2010) for some other context.

3.2.3 Study of variation of speed with respect to various parameters

This part actually shows how speed of an NMV varies with respect to various parameters like

- Number of PCUs in same strip.
- Number of PCUs in both adjacent strips.
- Distance of test vehicle from road edge.

For this study two locations were selected namely;

1. Road near Rourkela main market, Rourkela
2. Road near Aambagan market, Rourkela.

Procedure followed here are

Video was played in KM player and cellophane paper was pasted on the screen. All 4 corners were marked and joined. The area was divided into equal number of strips. Then with respect to test vehicle (NMV), number of vehicles of different class in same and the both adjoining strip of strip in which test vehicle is there was noted. This process starts when test vehicle enters the section and this ends when test vehicle leaves the section. All vehicle classes were converted to one unit i.e. PCU. Speed of the test vehicle was calculated by ratio between times spent by it in the section to the distance covered. (I.e. length of section + length of the test vehicle) Then graph between speed of test vehicle and the three parameters were plotted. All the results are shown in section 3.3.3.

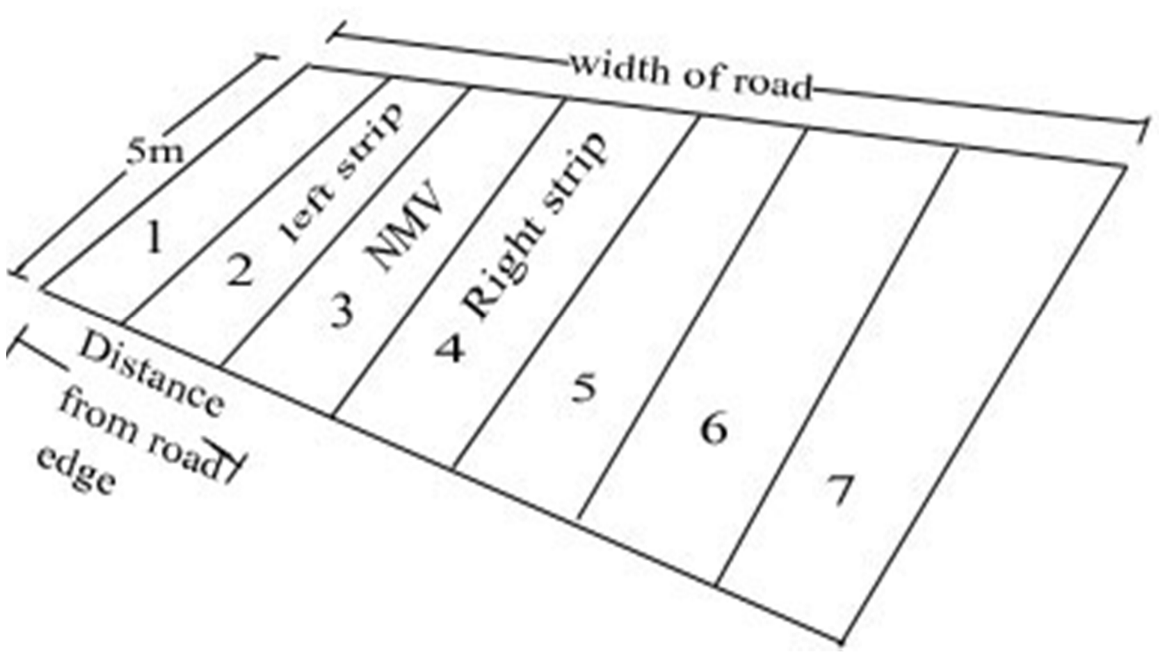


Fig 3.9 Road section study of speed with respect to various parameters

3.3 Results and discussion

This section gives the results obtained from the data extracted experimentally. There are three subsections separately for each kind of experimental work which are already defined above. The comparison as well as discussion of the results is also presented where ever required.

So the results for the experimental parts are presented one by one as follows.

3.3.1 Fundamental diagram

N.B Units for variables used in fig 3.10 to 3.21 are speed as m/s, density as PCU/m, and flow as PCU/sec respectively.

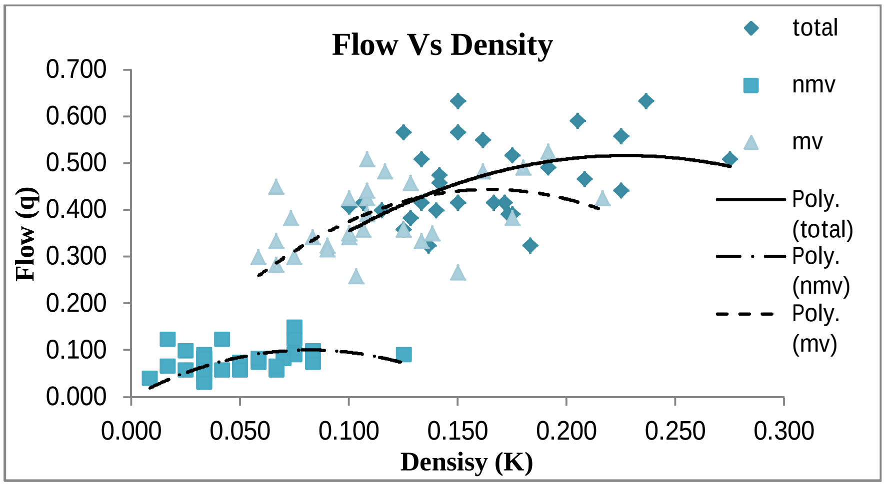


Fig 3.10 Flow versus density for road near Konark cinema hall

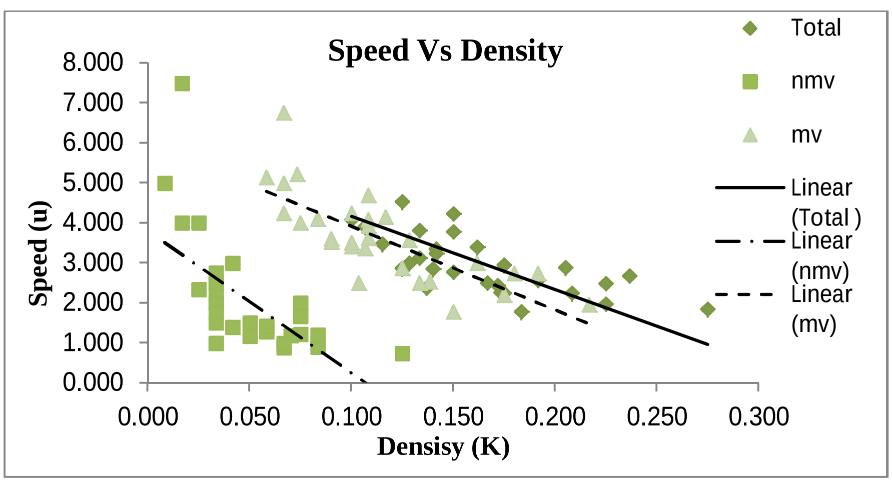


Fig 3.11 Speed versus density for road near Konark cinema hall

Fig 3.10 and fig 3.11 shows the flow versus density and speed versus density graphs for road near Konark cinema hall. In this location NMV percentage was found to be 17.03 % and total density was 4.87 PCU/m. The points obtained are for uncongested region so the speed values are high.

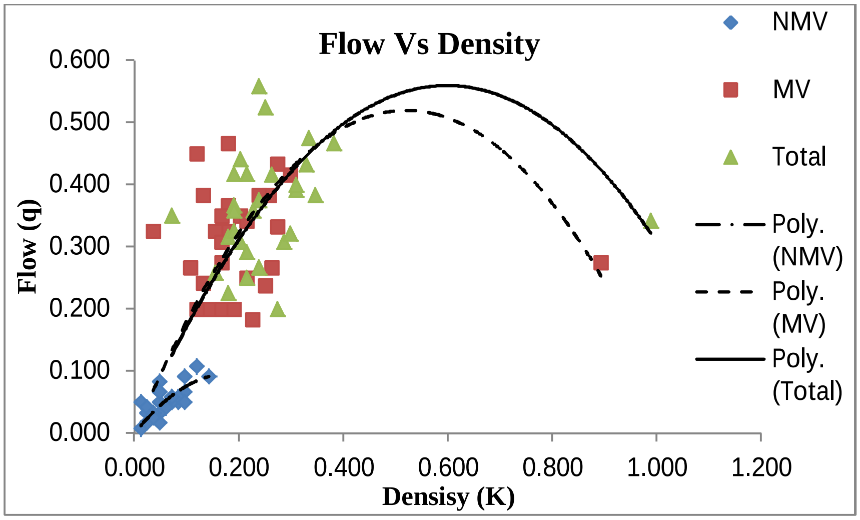


Fig 3.12 Flow versus density for road near Birsa chowk

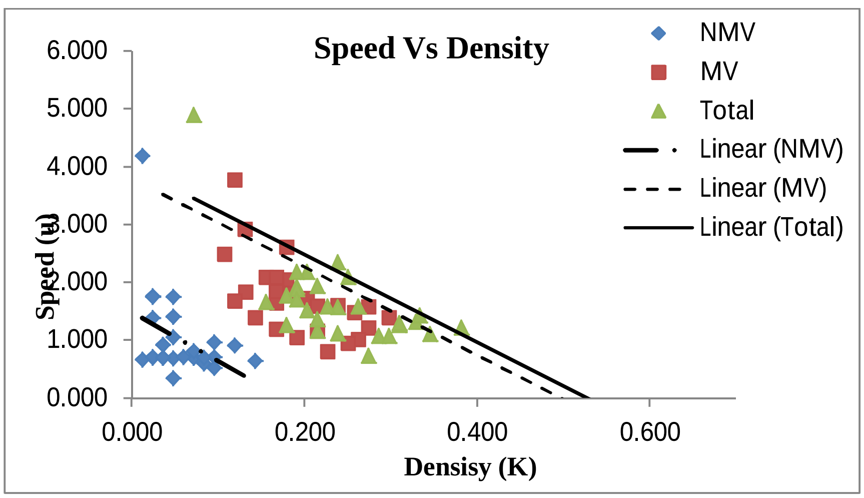


Fig 3.13 Speed versus density for road near Birsa chowk

Fig 3.12 and fig 3.13 shows the flow versus density and speed versus density graphs for road near Birsa chowk. In this location NMV percentage was found to be 13.11 % and total density was 7.93 PCU/m. Here motorized percentage was high with heavy vehicles like bus, trucks etc. So some points from the congested regions are also obtained. This is the reason for which the speed of the vehicles is of low range.

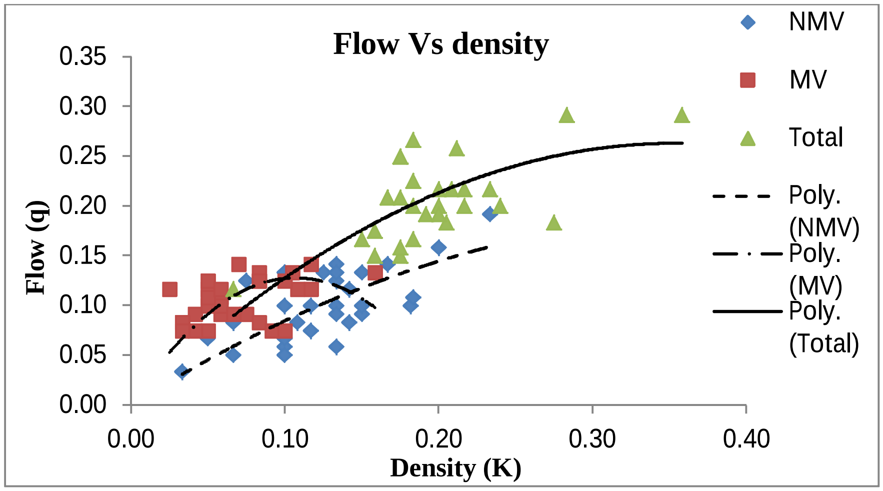


Fig 3.14 Flow versus density for upstream flow for main market Rourkela

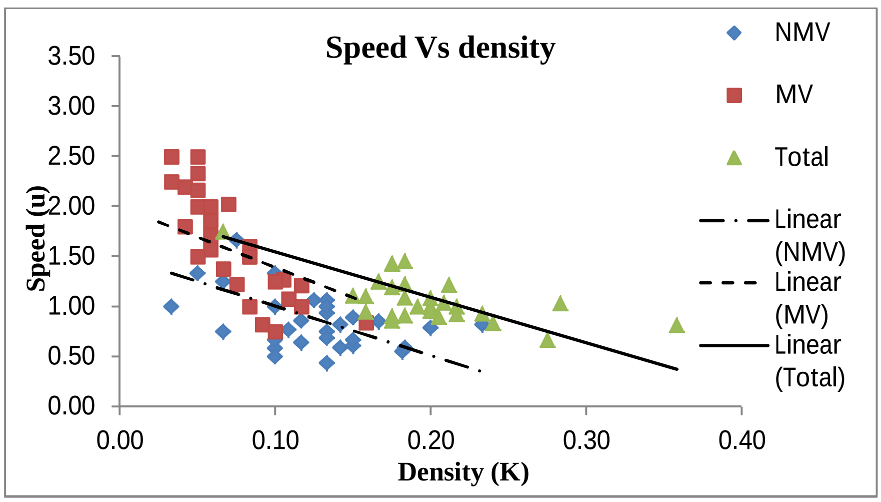


Fig 3.15 Speed versus density for upstream flow for main market Rourkela

Fig 3.14 and fig 3.15 shows the flow versus density and speed versus density graphs for upstream flow for main market Rourkela. In this location NMV percentage was found to be 48.73.03 % and total density was 5.87 PCU/m. The graphs are as expected. As NMV percentage is more so for motorized vehicles some points of congested flow was obtained.

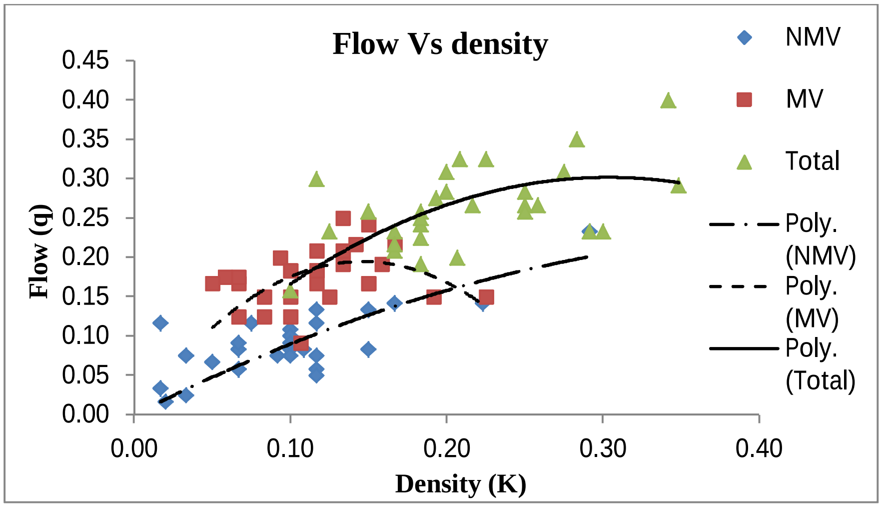


Fig 3.16 Flow versus density for downstream flow for main market Rourkela

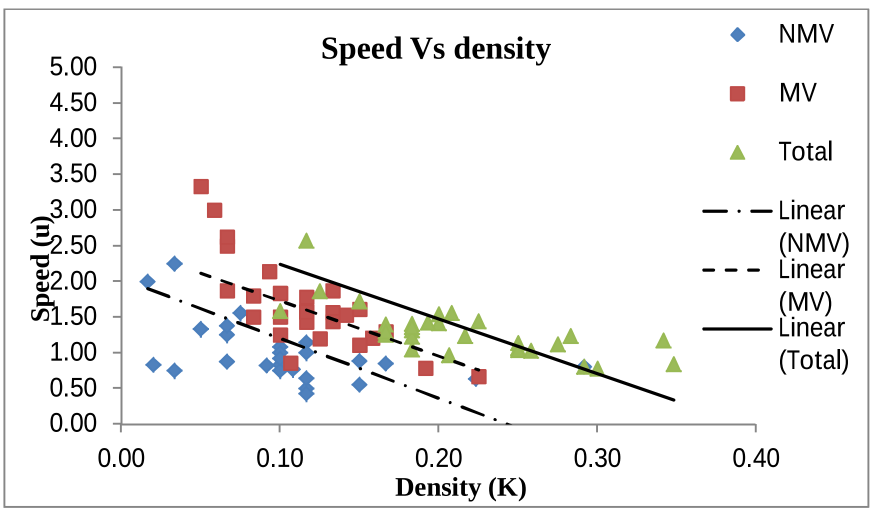


Fig 3.17 Speed versus density for downstream flow for main market Rourkela

Fig 3.16 and fig 3.17 shows the flow versus density and speed versus density graphs for downstream flow for main market Rourkela. In this location NMV percentage was found to be 33.75 % and total density was 6.35 PCU/m. The graphs are as expected. As NMV percentage is more so for motorized vehicles some points of congested flow was obtained. Also the speed values are less.

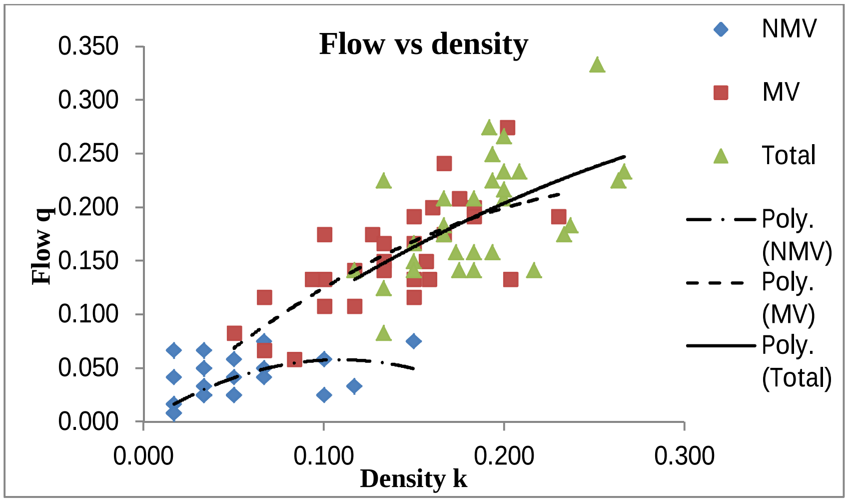


Fig 3.18 Flow versus density for upstream flow for road near Aambagan

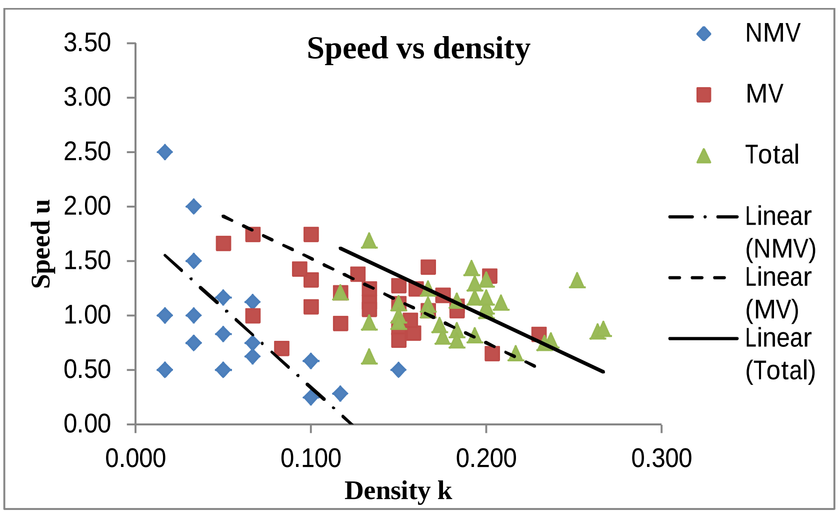


Fig 3.19 Speed versus density for upstream flow for road near Aambagan

Fig 3.18 and fig 3.19 shows the flow versus density and speed versus density graphs for upstream flow for road near Aambagan. In this location NMV percentage was found to be 33.64 % and total density was 6.58 PCU/m.

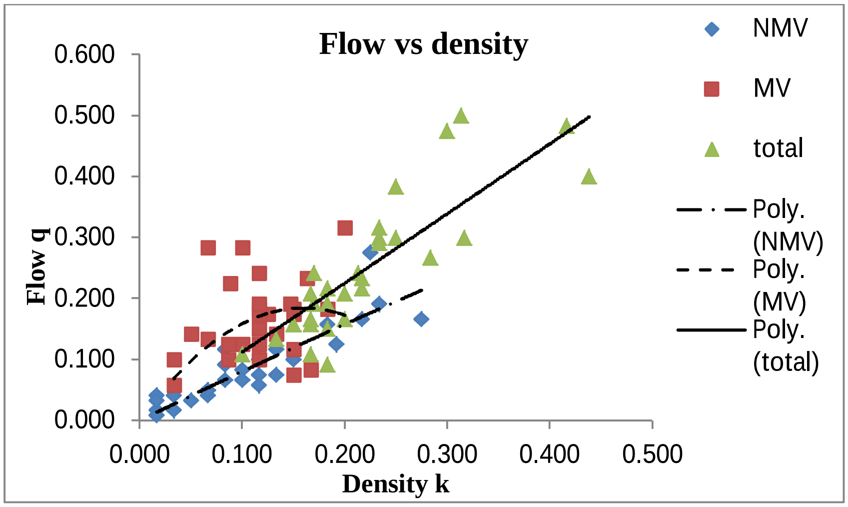


Fig 3.20 Flow versus density for downstream flow for road near Aambagan

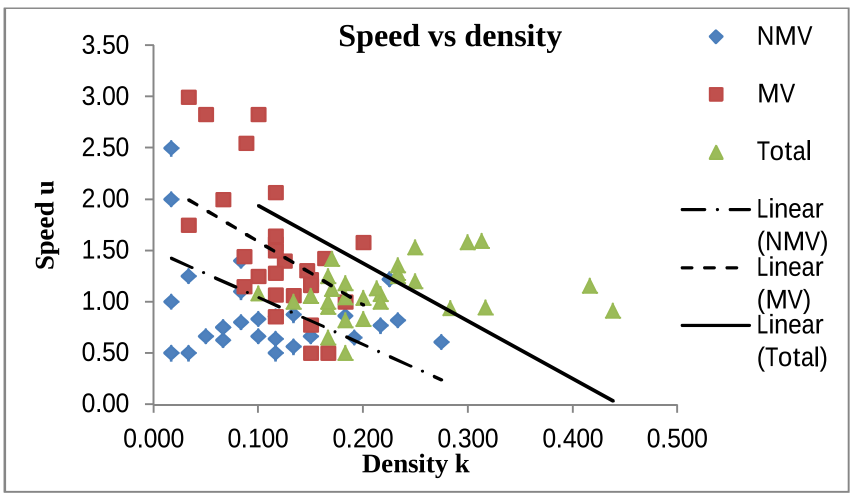


Fig 3.21 Speed versus density for downstream flow for road near Aambagan

Fig 3.20 and fig 3.21 shows the flow versus density and speed versus density graphs for downstream flow for road near Aambagan. In this location NMV percentage was found to be 18.89 % and total density was 5.61 PCU/m.

3.3.2 Lateral occupancy

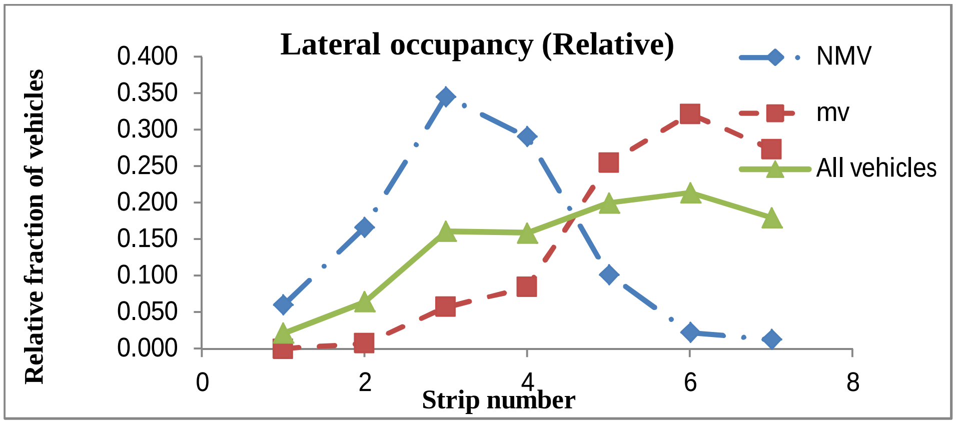


Fig 3.22 Lateral occupancy for road near Konark cinema hall

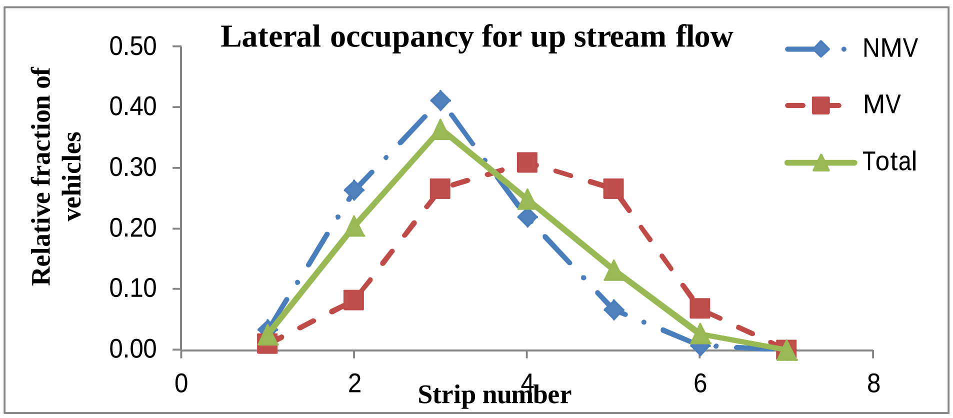


Fig 3.23 Lateral occupancy for up stream flow for road near Rourkela main market

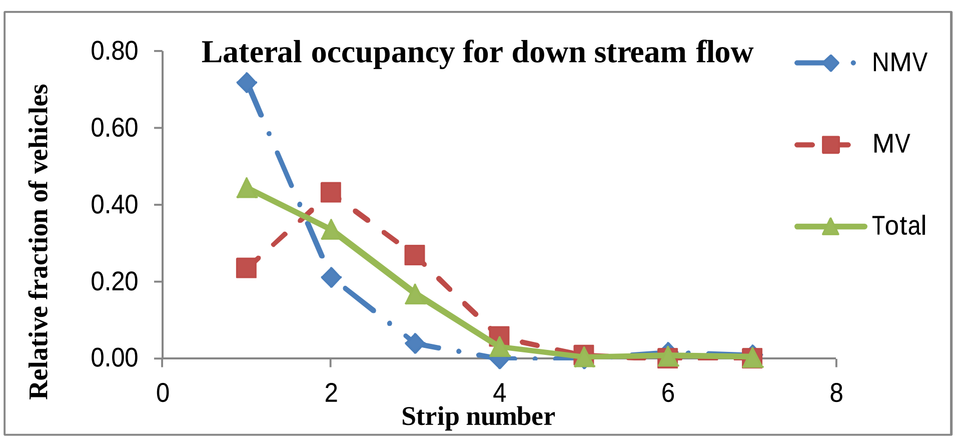


Fig 3.24 Lateral occupancy for downstream flow for road near Rourkela main market

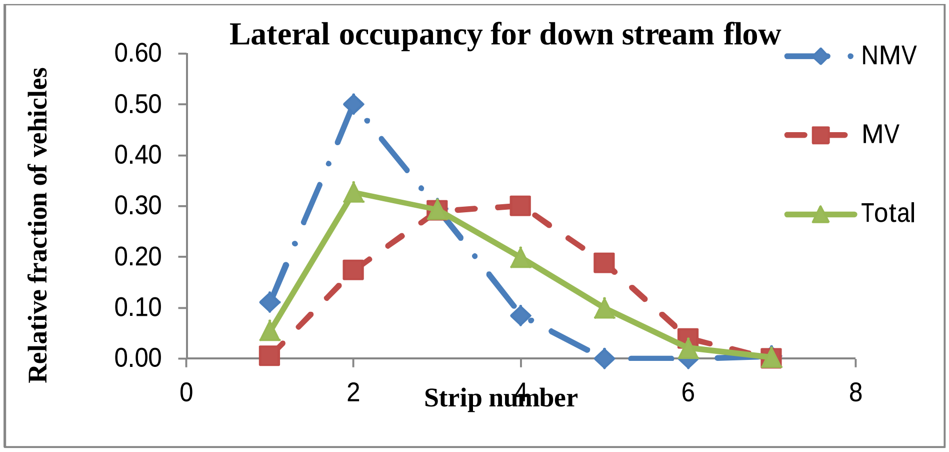


Fig 3.25 Lateral occupancy for downstream flow for near Aambagan

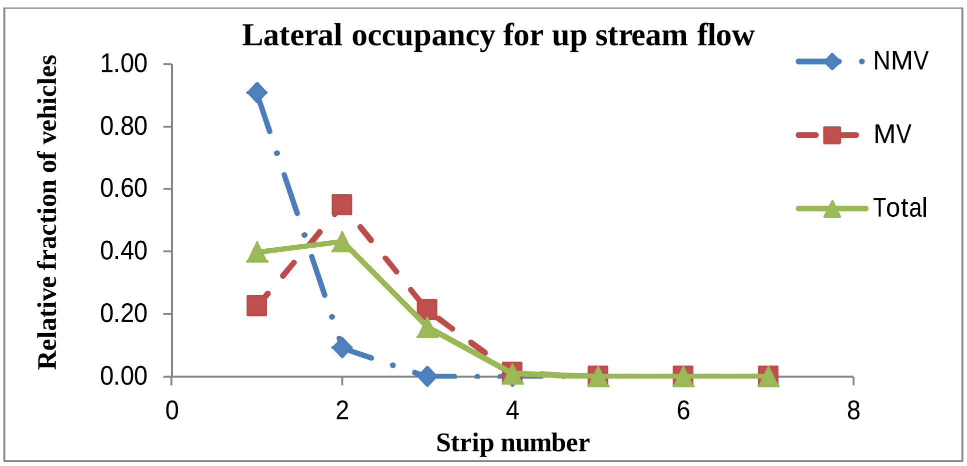


Fig 3.26 Lateral occupancy for upstream flow for near Aambagan

Fig 3.21 to fig 3.26 shows lateral occupancy graph. It can be seen that the NMVs trying to stay in left hand side of the road. As in India we follow left hand side drive the MVs try to overtake them and are found mostly in the right hand side of the road. Also the first strip or 1 m from the left edge remains almost empty because vehicles normally try to avoid moving at the edge when there are either no shoulders or raised curves are there. Roads in which there are shoulders the vehicles are found in the first strip from left hand side as well.

3.3.3 Speed versus various parameters

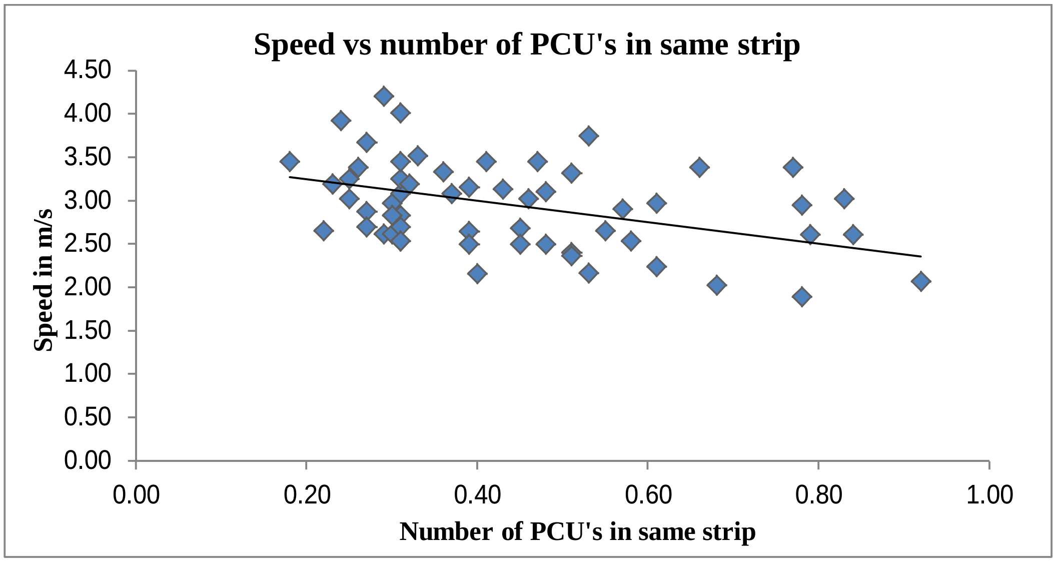


Fig 3.27 Speed versus number of PCU’s in same strip for road near main market

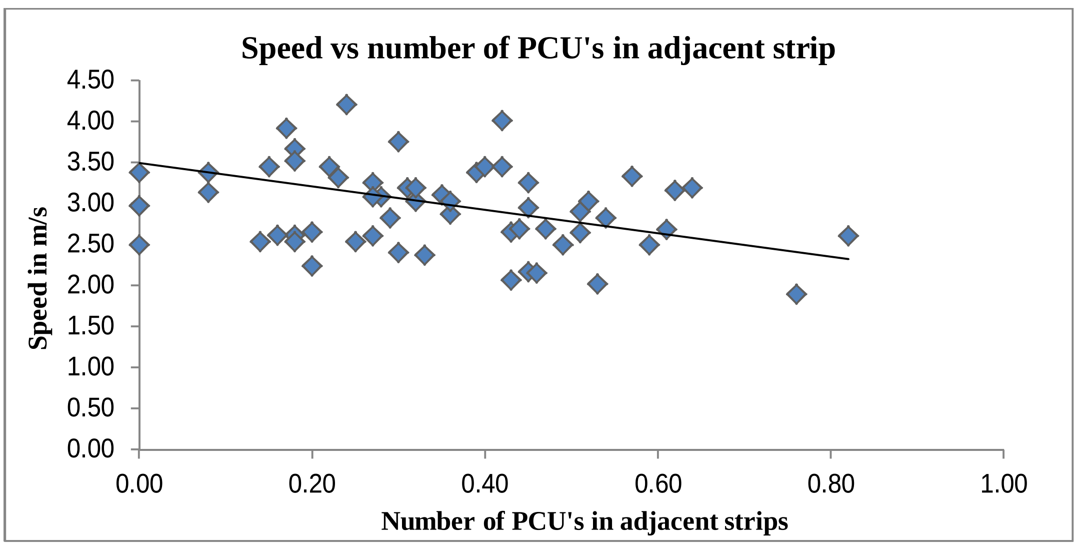


Fig 3.28 Speed versus number of PCU’s in alternate strip for road near main market

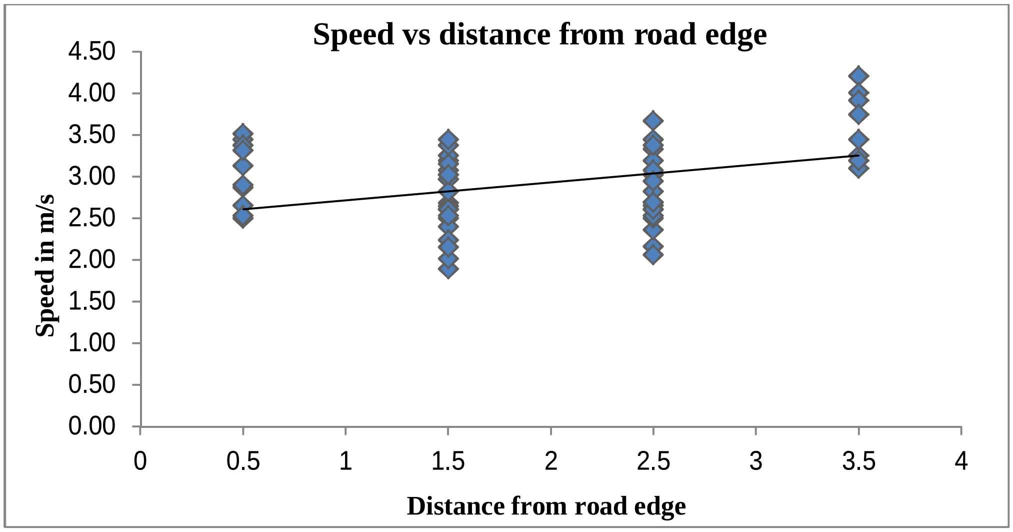


Fig 3.29 Speed versus distance from road edge for road near main market

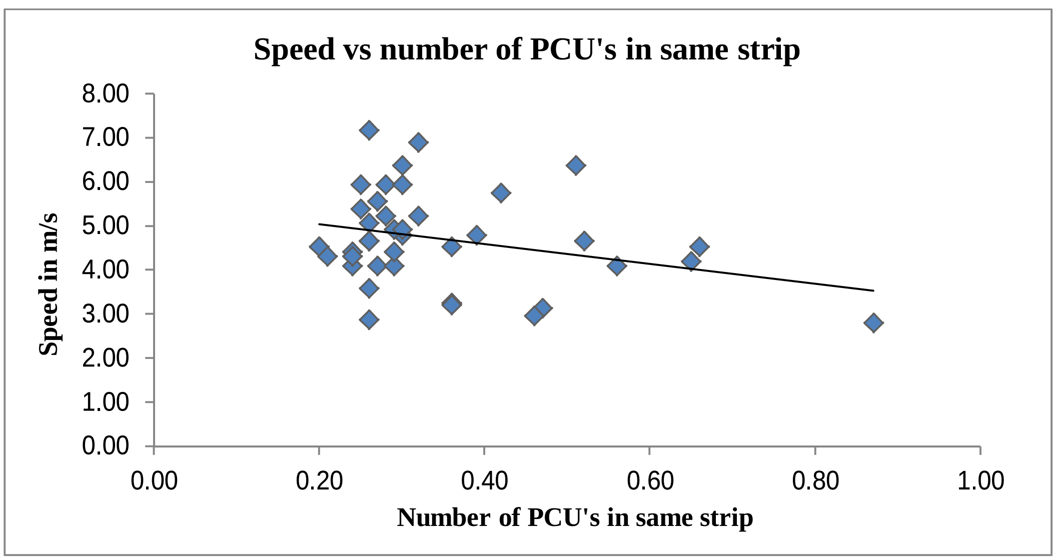


Fig 3.30 Speed versus number of PCU’s in same strip for road near Aambagan

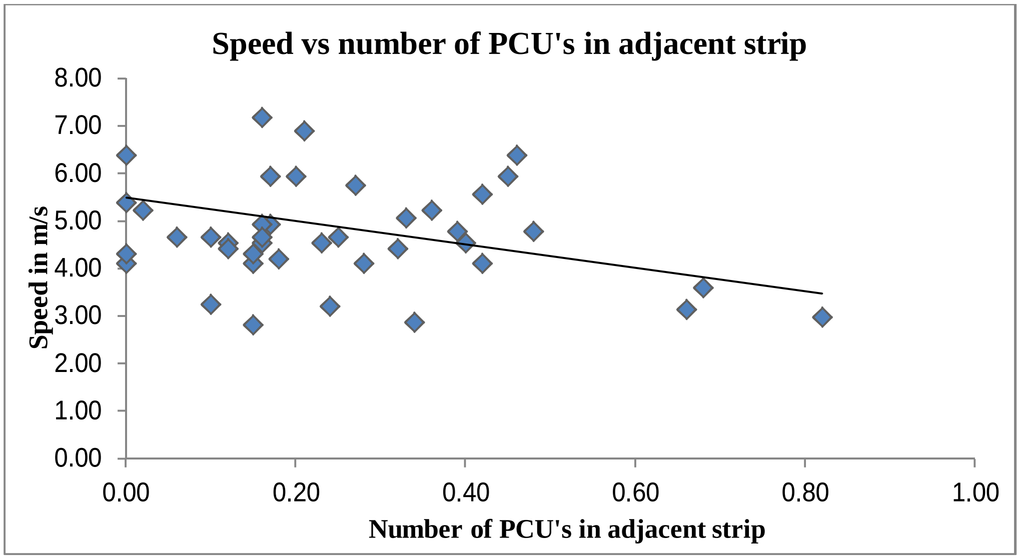


Fig 3.31 Speed versus number of PCU's in adjacent strip for road near Aambagan

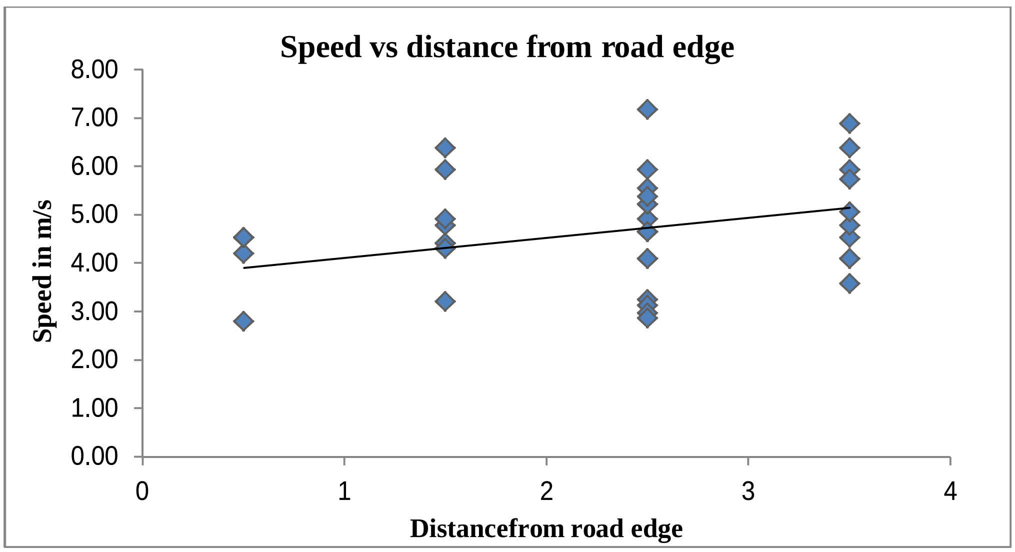


Fig 3.32 Speed versus distance from road edge for road near Aambagan

Fig 3.27 to fig 3.32 shows the graph for speed versus parameters. Form the graphs obtained experimentally it can be concluded that speed of an NMV decreases when number of PCU in same and adjacent strip increases. Speed decreases when distance from the road edge increases.

3.3.4 Comparison graphs

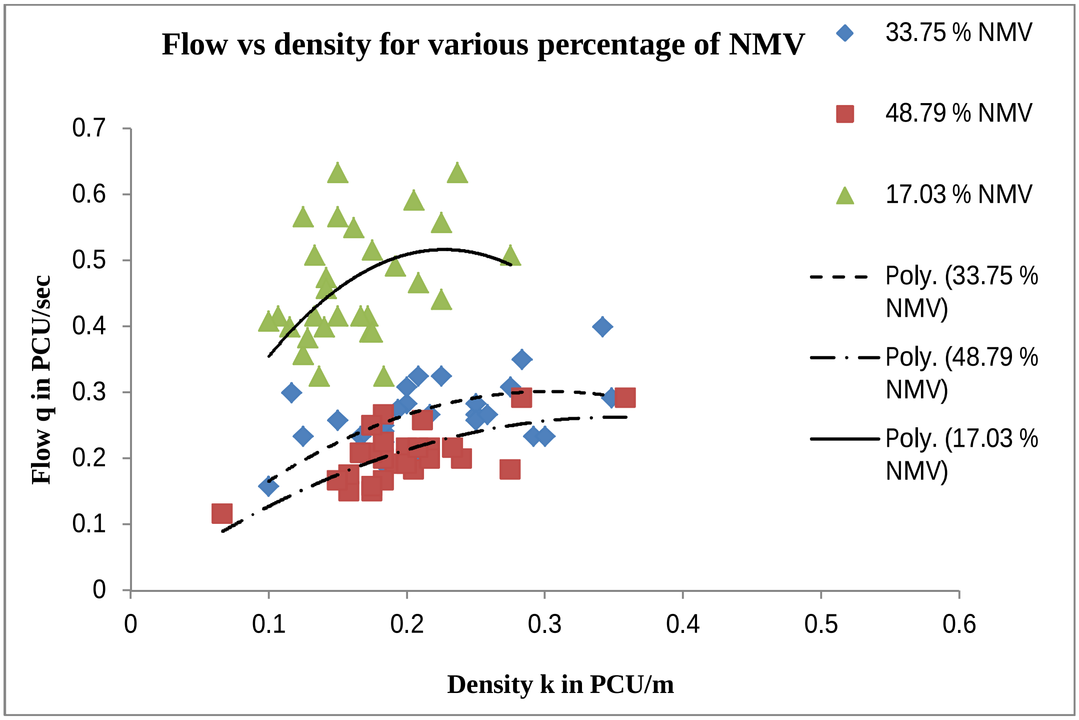


Fig 3.33 Flow versus density for various fraction of NMV

While comparing the flow versus density curve for various location with respect to various percentage of NMV it was found that that with increase in NMV fraction an adverse effect was noticed on the flow of the mixed traffic. Density decreases at a particular flow rate when NMV fraction increases.

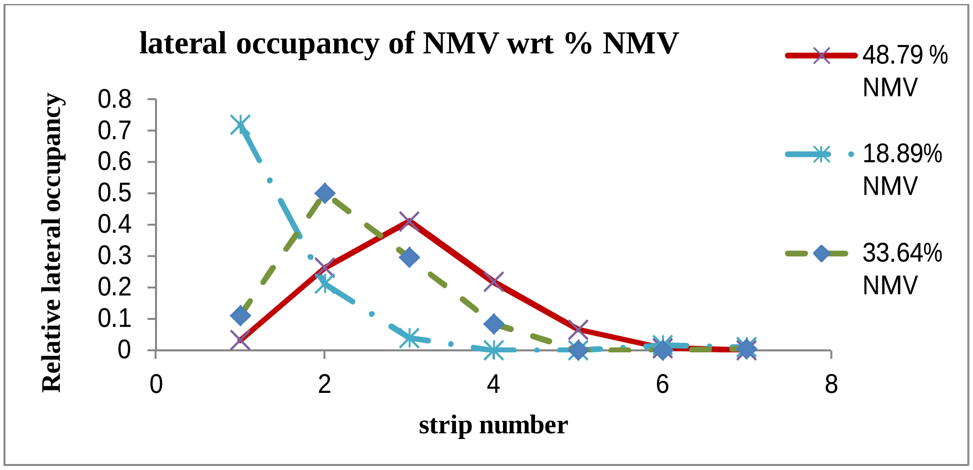


Fig 3.34 Comparison of lateral occupancy of MV with respect to NMV percentage

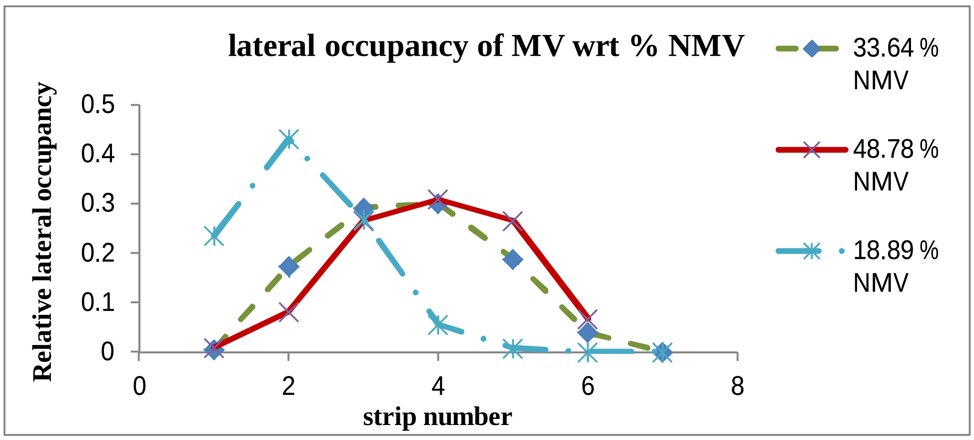


Fig 3.35 Comparison of lateral occupancy of MV with respect to NMV percentage

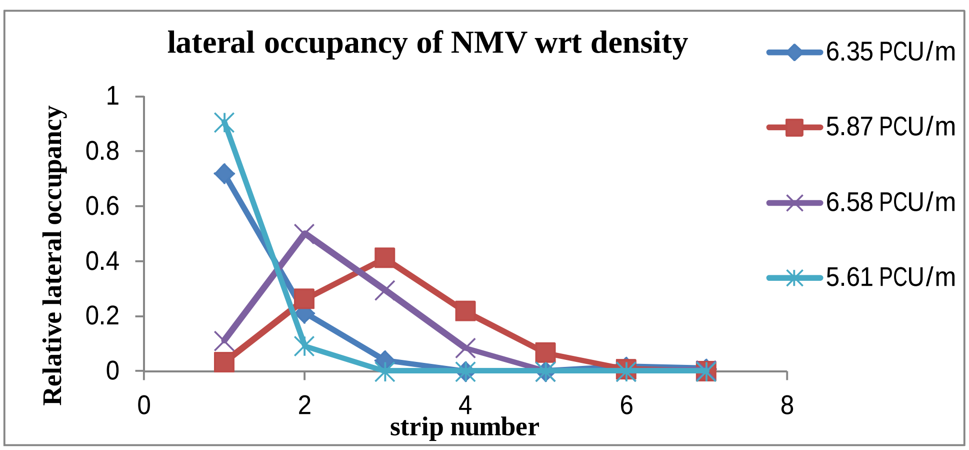


Fig 3.36 Comparison of lateral occupancy of NMV with respect to density.

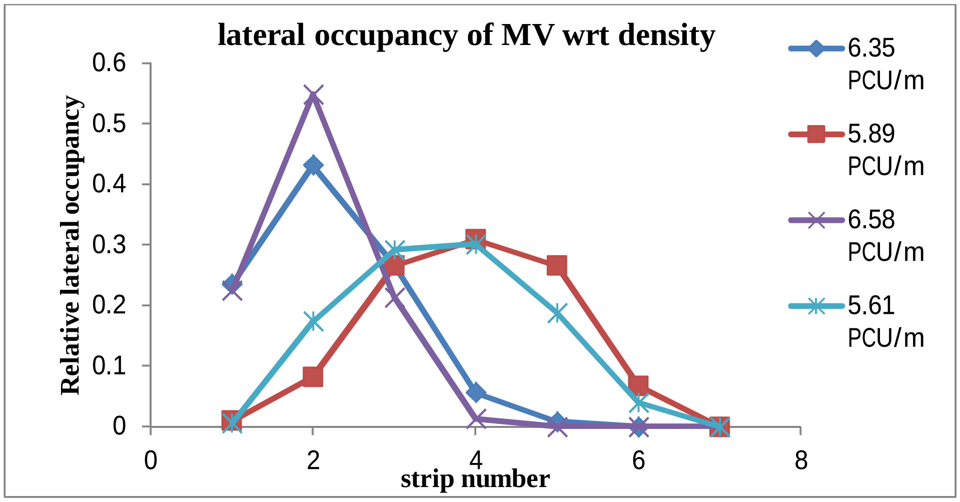


Fig 3.37 Comparison of lateral occupancy of MV with respect to density

Fig 3.34 and fig 3.35 show lateral occupancy of NMV and MV with respect to NMV percentage in that flow direction. Now with respect to percentage of NMV the predictions are like with less NMV percentage the non-motorised vehicles although found mostly in the left side i.e. strip 1 and 2 but are unevenly distributed. With moderate NMV percentage the non-motorized vehicle follow a trend and are segregated not only in the left but also found maximum in the middle part of the road occupying strip 2 and 3. With high NMV percentage the non-motorised vehicles are evenly distributed in the entire space and trying to occupy the right hand side of the road blocking the way for flow from other direction.

With less NMV percentage the motorised vehicles don’t face any problem and are evenly distributed in the entire flow space in that direction. With moderate NMV percentage motorised vehicles are trying to overtake the NMVs but as there is a flow from other direction as well so they are mostly occupying the middle part of their flow space i.e. strip 3 and 4. When NMV percentage is high then motorised vehicle try to overtake them and are found in right hand side of the road i.e. strip 4, 5 and 6 occupying the space for the flow from other direction as well.

Fig 3.36 and 3.37 show the lateral occupancy of NMV and MV with respect to density. Density data obtained from all the location are almost same, so it is not possible to predict the trend of lateral occupancy.

Chapter 4

Proposed Model

This section is about the proposed model, where an attempt has been made to model the speed data obtained experimentally with respect to the various parameters mentioned in chapter 3. Before moving into the model it's necessary to know about fuzzy logic because it has been used as a tool for linguistic classification of various input and/or output parameters inside the model.

Hence this section includes a brief introduction to fuzzy logic followed by the basic structure of the proposed model.

4.1 Introduction to fuzzy logic

Fuzzy logic was first introduced in the year 1965, by Lotfi A. Zadeh [17] , professor for computer science at the University of California in Berkeley. Fuzzy Logic is actually multi valued logic. It has some intermediate values in between conventional evaluations like true/false, yes/no, high/low, etc. Fuzzy deals with reasoning that is approximate rather than exact. In binary sets we have two-valued logic i.e. either true or false, where as in fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic is used to handle the concept of partial truth. Here the truth value has a range between completely true and completely false.

Fuzzy systems are very useful in two general contexts:

- In situations involving highly complex systems whose behaviours are not well understood.
- In situations where an approximate, but fast, solution is required.

4.1.1 Fuzzy set and crisp set

A crisp set is a collection of similar elements with same group properties, where the belonging to the group is complete without any doubt.

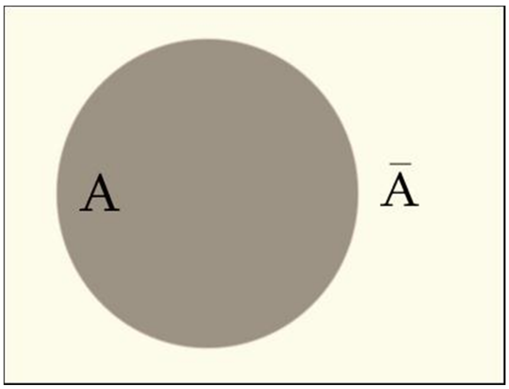


Fig 4.1 Crisp set

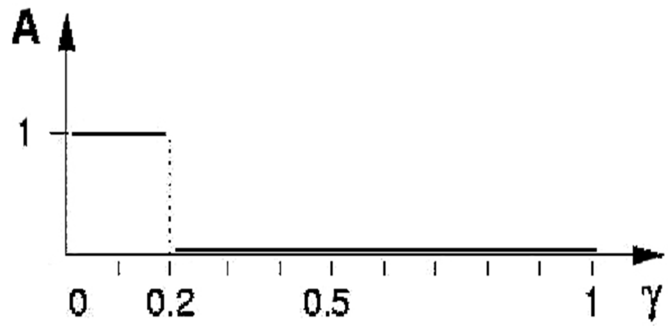


Fig 4.2 Characteristic Function of a Fuzzy Set

A crisp set *A* can be defined as

$$A = \{x \mid x \in X\}$$

Where, *x* is an element of the set and *X* is the common property of the set.

A fuzzy set is a set, where belonging to that group may or may not be complete. The main difference between a crisp set and a fuzzy set is the nature of their boundary. In a crisp set, the boundary is well defined. But in case of a fuzzy set, the boundary is a blur region. The degree with which an element belongs to a set is defined by a membership value. This membership value is obtained using some membership function. For a crisp set, the membership value is either 1 or 0. For a fuzzy set, it is any value in between 0 to 1.

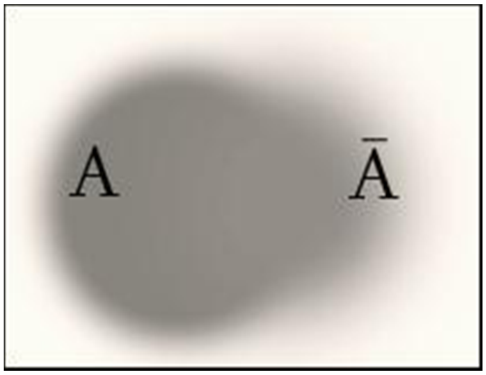


Fig 4.3 Fuzzy set

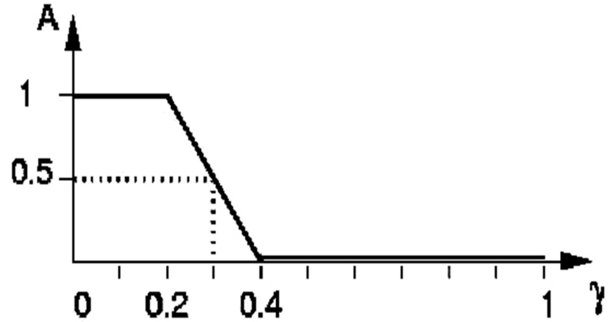


Fig 4.4 Characteristic Function of a Fuzzy Set

Fuzzy set $\tilde{A}$ can be defined as

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$$

Where, $\mu_{\tilde{A}}$ is called the membership function of x in set $\tilde{A}$, value of $\mu_{\tilde{A}}$ is in between 0 to 1.

4.1.2 Operations on fuzzy set

There are three basic set operations for fuzzy sets; they are union, intersection and complement.

Union

Let there be two fuzzy sets $\tilde{A}$ and $\tilde{B}$, their union $\tilde{C}$ will be such that the membership function of $\tilde{C}$ is maximum between the membership functions of $\tilde{A}$ and $\tilde{B}$, i.e.

$$\mu_{\tilde{C}}(x) = Max\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\}$$

Intersection

If there are two fuzzy sets $\tilde{A}$ and $\tilde{B}$, and there intersection is $\tilde{D}$ such that the membership function of $\tilde{D}$ is the minimum of the membership functions of $\tilde{A}$ and $\tilde{B}$, i.e.

$$\mu_{\tilde{D}}(x) = Min\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\}$$

Complement

For a fuzzy set $\tilde{A}$, its complement $\overline{\tilde{A}}$ is such that,

$$\mu_{\overline{\tilde{A}}}(x) = 1 - \mu_{\tilde{A}}(x)$$

As boundary of $\tilde{A}$ is not crisp, then boundary of $\overline{\tilde{A}}$ is also not crisp i.e.

$$\tilde{A} \cap \overline{\tilde{A}} \neq \phi$$

$$\tilde{A} \cup \overline{\tilde{A}} \neq X$$

Where, ϕ is the Null set.

4.1.3 Fuzzy Arithmetic

Fuzzy arithmetic means arithmetic applicable to fuzzy numbers. One fuzzy arithmetic namely weighted average was used in the proposed model. Let there are N number of fuzzy numbers, $\tilde{M}_i$ (i = 1 to N), in R, having weight w_i (say); then the weighted average is given by

$$\overline{M} = \frac{\sum_{i=1}^{N} w_i.\tilde{M}_i}{\sum_{i=1}^{N} w_i}$$

4.1.4 Truth Value and membership function

As already stated an element of a set may belong partially to a set, Fuzzy logic uses infinite number of logic variables including true and false. We can say fuzzy logic is somehow the generalized version of classical logic. Every element in a fuzzy set has some truth value, which is represented on a scale of 0 to1. In other words if the proposition is true, the value is 1 and if it is false the value is 0. Any value in between indicates its degree of truth or its membership in the fuzzy set.

Any function representing this membership or truth value is called membership function.

For example a set H of students with height of about 6 feet. Since the property near 6 feet is fuzzy, there is not a unique membership function for H. Its membership function is represented by μ_H. In this case those students having exactly 6 feet are complete member of the set H, with a membership value or truth vale 1. Others will have a membership value nearer to one as the approach 6 feet. The membership function for this example is shown graphically below. Value of H1 and H2 are user defined depending on the importance of result.

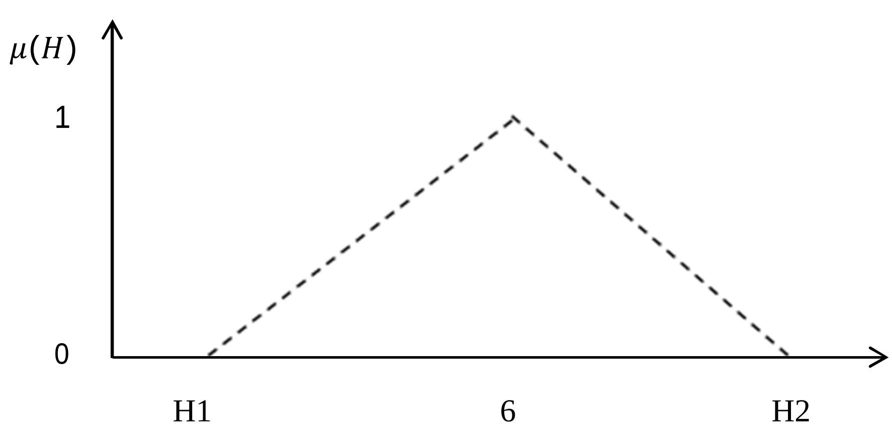


Fig 4.5 Membership function for given example

4.1.5 Logical Connectives

Logical connectives are used to connect multiple propositions. The term AND and OR are two logical connectives.

$$|\, x_1 \text{ is } A_1 \text{ AND } x_2 \text{ is } A_2 \,|=|\, x_1 \text{ is } A_1 \,| \wedge |\, x_2 \text{ is } A_2 \,|$$

$$|\, x_1 \text{ is } A_1 \text{ OR } x_2 \text{ is } A_2 \,|=|\, x_1 \text{ is } A_1 \,| \vee |\, x_2 \text{ is } A_2 \,|$$

Where, “x_i is A_i” is a proposition.

$\wedge$ And $\vee$ denote the MIN and MAX operators respectively.

4.1.6 Premise Variable

In general sense the input parameters are called the premise variable. Propositions representing the prevailing conditions are known as premise variable. It carries a value but they need to be grouped according to their membership values.

4.1.7 Consequence Variable

These are the output parameters. For a particular combination of premise variables there exists a course of action, which is in fuzzy logic known as consequence variable. It’s a fuzzy number which represents the course of action. This fuzzy number must be approximately same as a crisp value; otherwise defuzzyfication has to be done.

4.1.8 Implication and Reasoning

The prevailing conditions in form of premise variables are connected through rules to get consequence variable followed by the course of action. For a particular set of premise variables, there should be a unique value of consequence variable, connected by a fuzzy rule denoting a particular course of action. This action is the conclusion of the fuzzy logic.

If the a set of premise variables satisfies more than one rule then, the course of action is determined by taking weighted average of the consequence variables of all those rules.

In this the course of action is determined.

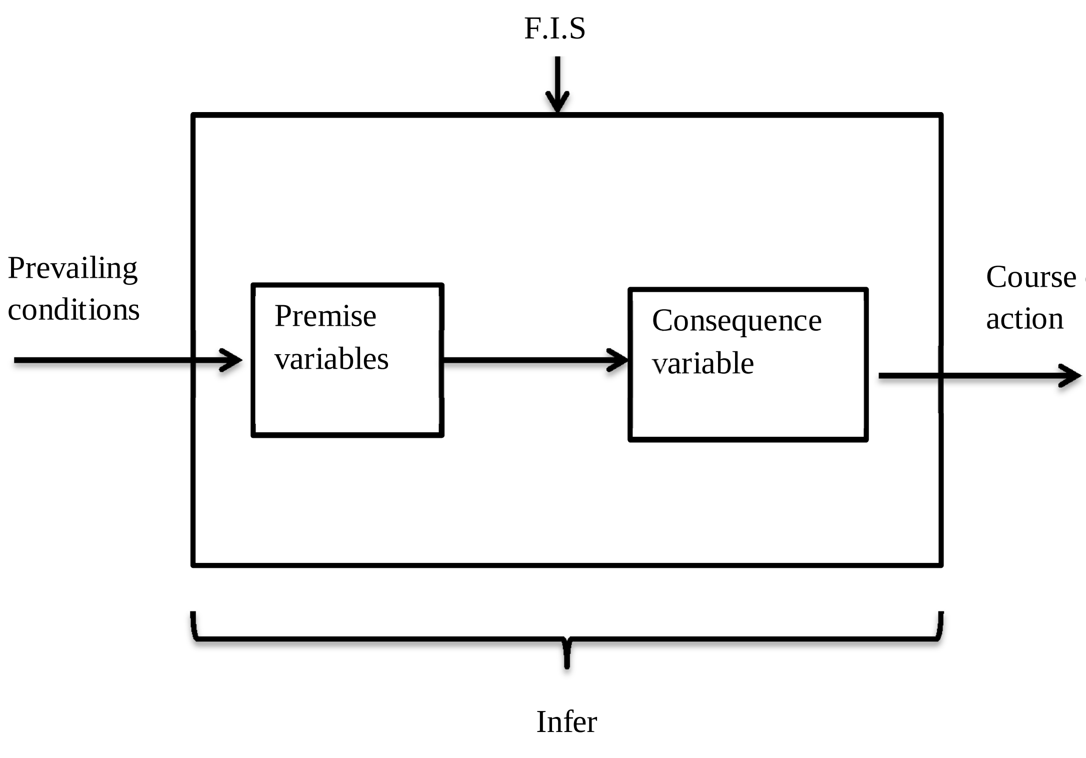


Fig 4.6 Fuzzy inference system

4.2 Basic structure of the proposed model

This section gives an idea about the generalized structure of the proposed model. This model is to simulate the speed versus various parameters as stated in chapter 3; an experimental observation was done to see how speed of a non-motorized vehicle varies according to various parameters like

- Number of PCUs in same strip.
- Number of PCUs in both adjacent strips.
- Distance of test vehicle from road edge.

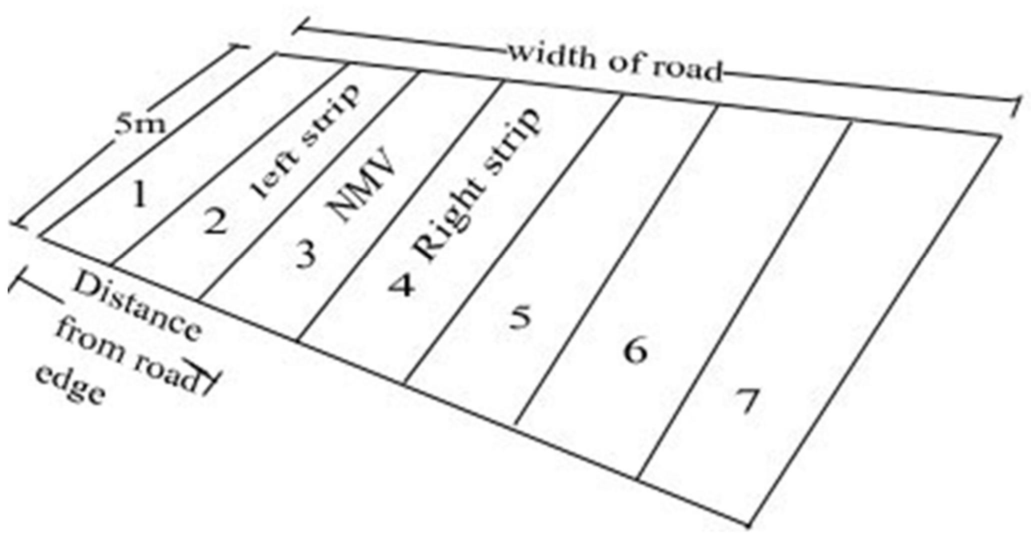


Fig 4.7 road section for study of speed versus various parameters

The width of the road was divided into strips of width 1 meter. The strip in which the non-motorized test vehicle is moving is named as same strip. The strips just next to that strip in both left hand and right hand side are named as adjacent strips. The distance of test vehicle from the left edge of the road is named as distance from road edge. These 3 parameters are the input parameters, which are responsible for the speed of the test vehicle as an output of the model.

4.2.1 Modeling the inference system

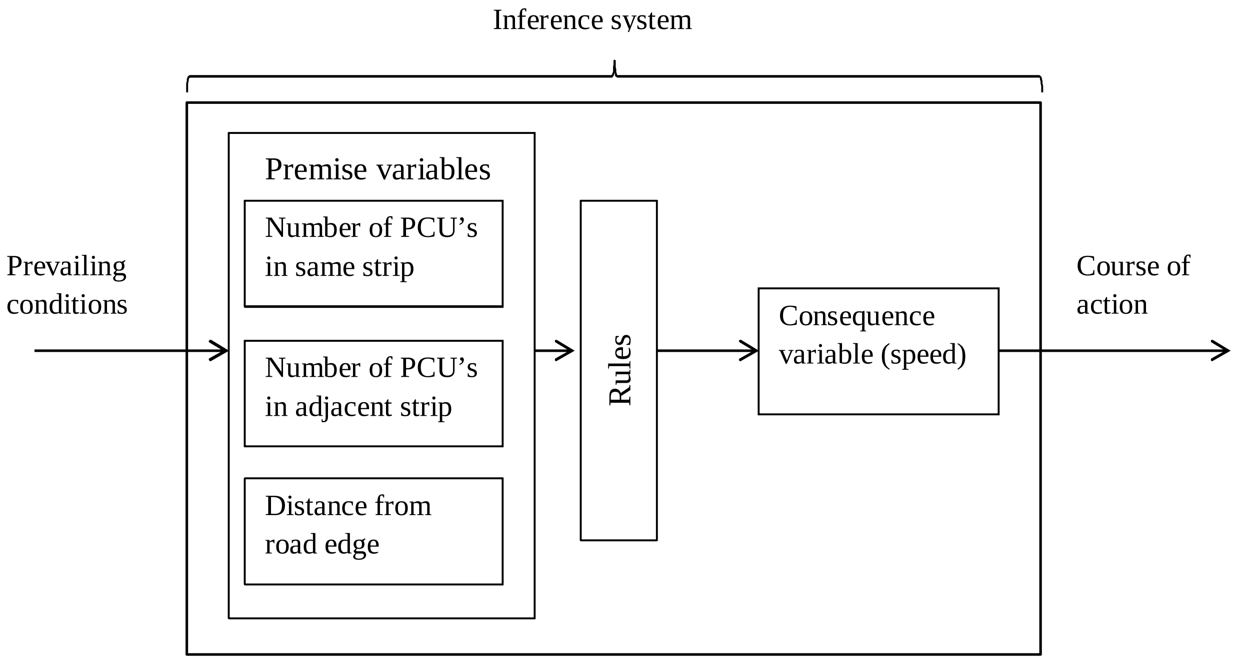


Fig 4.8 Structure of the model

The figure above gives a complete idea about the model. Each part of the system is described one by one in the following sub sections.

4.2.1.1 Premise variables and their linguistic classification

From the prevailing condition we got three input parameters as premise variables. They are as follows;

- Number of PCUs in same strip. (s_z)
- Number of PCUs in both adjacent strips. (a_z)
- Distance of test vehicle from road edge. (d_z)

Number of PCUs in same strip (s_z) is the number of vehicles (in terms of PCU) in the same strip in which our test vehicle is moving. It is linguistically classified into 3 groups, namely Large number, Moderate number, few number. The three linguistic classes are described as fuzzy sets defined on s_z.

For few number

$$\mu_f(s_z) = \begin{cases} 1; \ s_z \leq s_z^1 \\ \dfrac{s_z^2 - s_z}{s_z^2 - s_z^1}; s_z^1 < s_z \leq s_z^2 \\ 0; \ s_z \geq s_z^2 \end{cases}$$

For moderate number

$$\mu_m(s_z) = \begin{cases} 0; \ s_z \leq s_z^1 \\ \dfrac{s_z - s_z^1}{s_z^2 - s_z^1}; \ s_z^1 < s_z \leq s_z^2 \\ \dfrac{s_z^3 - s_z}{s_z^3 - s_z^2}; \ s_z^2 < s_z \leq s_z^3 \\ 0; \ s_z \geq s_z^3 \end{cases}$$

For large number

$$\mu_l(s_z) = \begin{cases} 0; \ s_z \leq s_z^2 \\ \dfrac{s_z - s_z^2}{s_z^3 - s_z^2}; s_z^2 < s_z \leq s_z^3 \\ 1; \ s_z \geq s_z^3 \end{cases}$$

It may be noted that the values of the limits s_z^1 , s_z^2, s_z^3 can be decided through a trial and error process. The actual values used in the model are described in chapter 5.

The Number of PCUs in both adjacent strips (a_z) is the number of vehicles (in terms of PCU) in both left and right strip adjacent to the strip in which the test vehicle is moving. It is divided into three linguistic classes, namely, high number, moderate number, less number. The three linguistic classes are described as fuzzy sets defined on a_z.

For less number

$$\mu_l(a_z) = \begin{cases} 1; \ a_z \le a_z^1 \\ \dfrac{a_z^2 - a_z}{a_z^2 - a_z^1}; a_z^1 < a_z \le a_z^2 \\ 0; \ a_z \ge a_z^2 \end{cases}$$

For moderate number

$$\mu_m(a_z) = \begin{cases} 0; \ \ a_z \le a_z^1 \\ \dfrac{a_z - a_z^1}{a_z^2 - a_z^1}; \ a_z^1 < a_z \le a_z^2 \\ \dfrac{a_z^3 - a_z}{a_z^3 - a_z^2}; \ a_z^2 < a_z \le a_z^3 \\ 0; \ \ a_z \ge a_z^3 \end{cases}$$

For high number

$$\mu_h(a_z) = \begin{cases} 0; \ a_z \le a_z^2 \\ \dfrac{a_z - a_z^2}{a_z^3 - a_z^2}; a_z^2 < a_z \le a_z^3 \\ 1; \ a_z \ge a_z^3 \end{cases}$$

It may be noted that the values of the limits a_z^1, a_z^2, a_z^3 can be decided through a trial and error process. The actual values used in the model are described in chapter 5

The **Distance of test vehicle from road edge** (d_z) is the distance between the left edges of road to the center line of the strip in which the test vehicle is moving. It is divided into three linguistic classes, namely, near, far, very far. The three linguistic classes are described as fuzzy sets defined on d_z.

For near

$$\mu_n(d_z) = \begin{cases} 1; d_z \leq d_z^1 \\ \dfrac{d_z^2 - d_z}{d_z^2 - d_z^1}; d_z^1 < d_z \leq d_z^2 \\ 0; d_z \geq d_z^2 \end{cases}$$

For far

$$\mu_f(d_z) = \begin{cases} 0; d_z \leq d_z^1 \\ \dfrac{d_z - d_z^1}{d_z^2 - d_z^1}; d_z^1 < d_z \leq d_z^2 \\ \dfrac{d_z^3 - d_z}{d_z^3 - d_z^2}; d_z^2 < d_z \leq d_z^3 \\ 0; d_z \geq d_z^3 \end{cases}$$

For very far

$$\mu_{vf}(d_z) = \begin{cases} 0; d_z \leq d_z^2 \\ \dfrac{d_z - d_z^2}{d_z^3 - d_z^2}; d_z^2 < d_z \leq d_z^3 \\ 1; d_z \geq d_z^3 \end{cases}$$

It may be noted that the values of the limits d_z^1, d_z^2, d_z^3 can be decided through a trial and error process. The actual values used in the model are described in chapter 5.

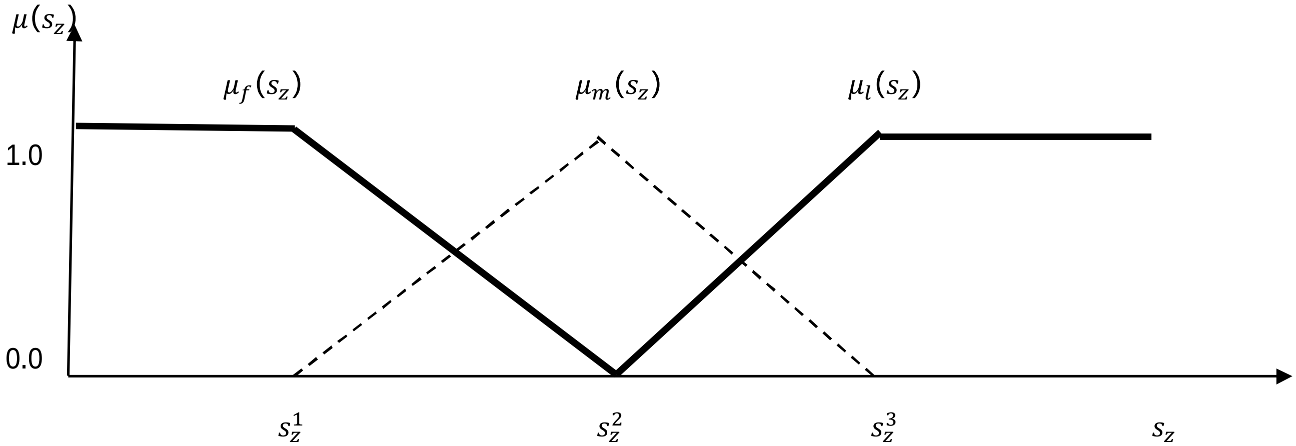


Fig 4.9 Membership functions for sets of number of PCUs in same strip

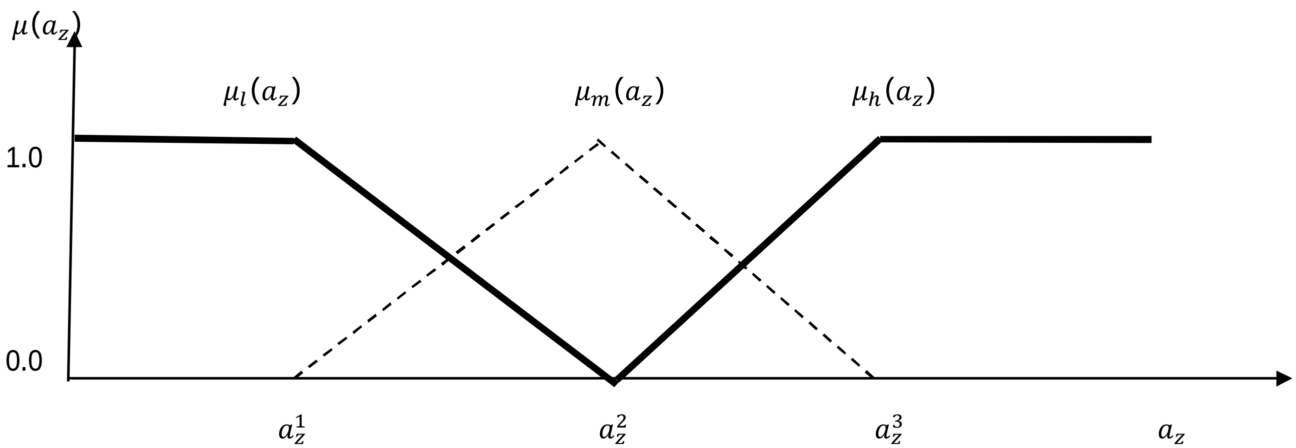


Fig 4.10 Membership functions for sets of number of PCUs in both adjacent strips

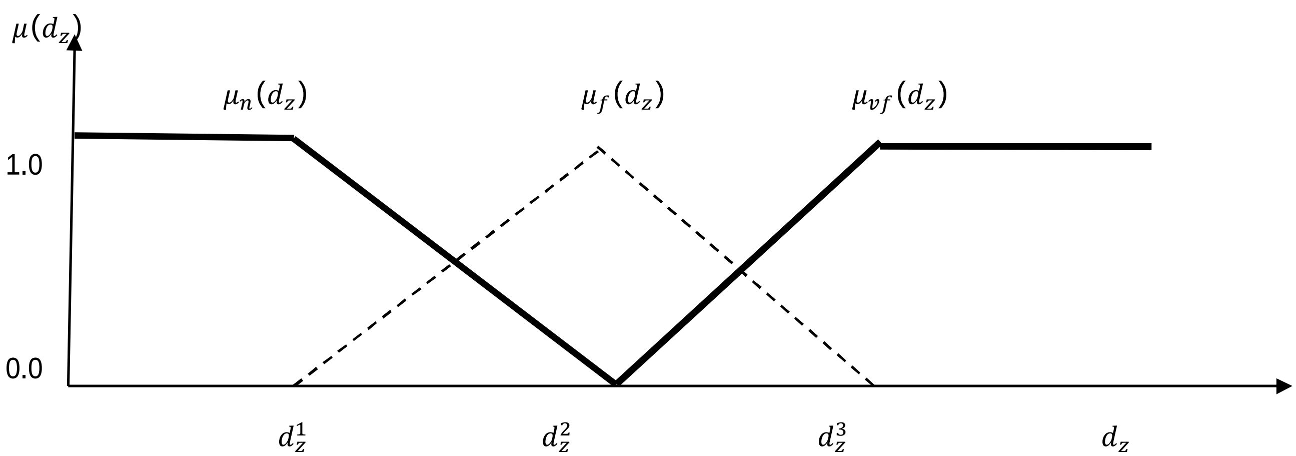


Fig 4.11 Membership functions for sets of distance of test vehicle from road edge

4.2.1.2 Consequence variable

The consequence variable in this fuzzy inference system represents the speed at which the vehicle will move. This is taken on a scale of S. As there are 27 rules hence there are 27 S values i.e. S_1, S_2, S_3…..S_{27}. The values of S_1, S_2…..S_{27} were decided as per the speed data obtained experimentally. All exact values of S used in the project are given chapter 5.

4.2.1.3 Rules of the fuzzy inference system

The fuzzy inference system developed here relates the premise variables to the consequence variable, through a set of rules. In this inference system there are total 27 rules each relating a particular combination of the premise variables to some S value; for example,

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is near

Then Speed will be S_1.

The rules are based on following principles;

1. S decreases as number of PCU’s in the same strip increases.

2. S decreases as number of PCU’s in the adjacent strip increases.

3. S increases as distance from road edge increases.

If any input data satisfies more than one rule then weighted average is taken

$$\mathbf{D(k)}=\sum\left(\frac{w_{r,k}}{\sum w_{r,k}}S_r\right)$$

Where, $w_{r,k}$ is the weight of the r^{th} membership Subset with input set k.

S_r is the consequence. Weight of a membership subset, $w_{r,k}$=min{ $\mu(s_z)$, $\mu(a_z)$, $\mu(d_z)$ }

The figure below shows the mapping between premise and consequence variable. To maintain clarity all 27 rules are not shown.

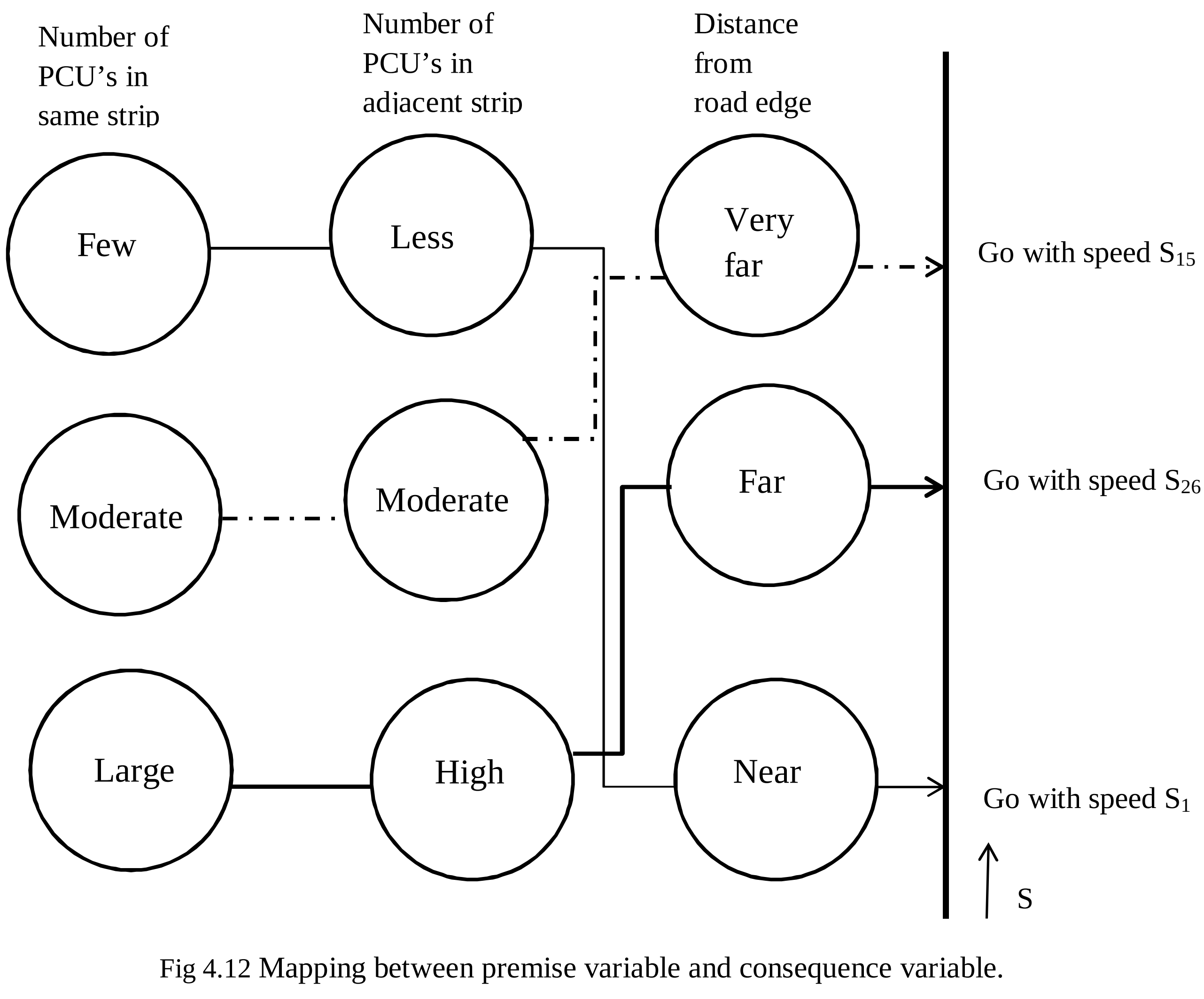


Fig 4.12 Mapping between premise variable and consequence variable.

Chapter 5

Simulation Results

In this chapter the simulation results on the basis of proposed model are presented. Along with that a flow chart of the model to show how the model is implemented for computer simulation. Model calibration to show how the user defined parameters i.e. the values adopted for membership function and values adopted for premise variable are shown. Also model validation is given. This part of the project is based on data obtained from road towards Rourkela main market and data obtained from road near aambagan (as stated in chapter 3).

5.1 Simulation

The structure of the proposed model is shown in chapter 4. On that basis a computer simulation or a program was developed. The simulation was done using C++. The compiler used was develop C++ version 4.9.9.2.

After defining all the parameters all the input data were inserted. Then the program automatically calculates the membership values for the particular set of inputs. As there are 27 rules, so weight for each membership subset (27 subsets) for a particular input set was calculated. Then weighted average of output value of each membership subset was calculated as per procedure given in section 4.2.1.3 of this thesis. This gives the final output value for that particular input set. Similarly the above procedure was followed for each input set and finally the parameters were printed in an output file. The complete procedure is presented in form of a flow chart in this section.

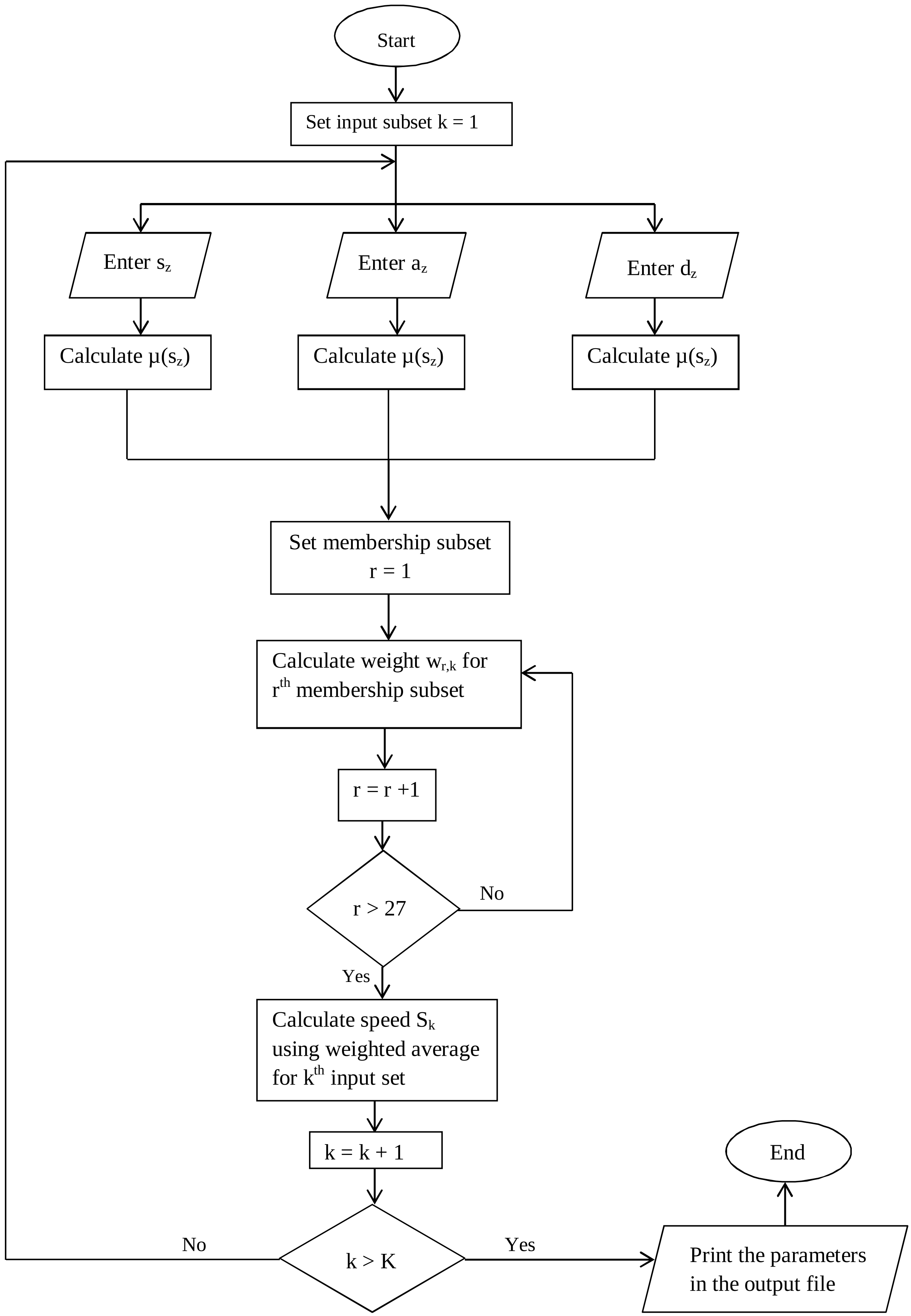


Fig 5.1 Flow chart for the proposed model

5.2 Model calibration

This section tells about how the model was calibrated i.e. what are the values adopted for the parameters defined in the model. Also the process used to arrive at the values chosen is described. The model was calibrated by using the data obtained from the road towards Rourkela main market.

Calibration refers to the various membership values taken i.e. the values of s_z^1, s_z^2, s_z^3, a_z^1, a_z^2, a_z^3, d_z^1, d_z^2, d_z^3 (defined in section 4.2.1.1). It also refers to the value adopted for the consequence variable i.e. the various S values. It also refers to the mapping between the premise and consequence variables i.e. the 27 rule adopted to get output

5.2.1 Calibration of the membership values

As stated before the model was calibrated according to the data obtained from road towards Rourkela main market. So the maximum and minimum values of each premise variable were noted from the experimental data. On a trial basis the values of s_z^1, s_z^2, s_z^3 were taken in the following manner;

$$s_z^1 \simeq s_z min + 1/4(s_z max - s_z min)$$

$$s_z^2 \simeq s_z min + 2/4(s_z max - s_z min)$$

$$s_z^3 \simeq s_z min + 3/4(s_z max - s_z min)$$

Where, $s_z min$ is the minimum $s_z$value obtained from experimental data.

$s_z max$ is the maximum $s_z$value obtained from experimental data.

Similarlar procedure was adopted for the other two premise variable. But it was seen this does not give the exact value, so to adjust the output values three values for all the limits was taken, one less than the adopted value and a bit higher than the adopted value.

So now all s_z^1 , s_z^2, s_z^3, a_z^1, a_z^2, a_z^3 , d_z^1, d_z^2, d_z^3 have three values each. Then various combinations of the values were taken, but at a time only one element will change and rest eight elements will have the same value. So in total there will be 3^9 set of combinations.

$$\begin{bmatrix} s_z^1 & s_z^2 & s_z^3 \\ a_z^1 & a_z^2 & a_z^3 \\ d_z^1 & d_z^2 & d_z^3 \end{bmatrix}$$

For each combination a set of speed value was obtained. Then square sum of difference value was found out i.e. square of the difference between experimental and simulated speed value was found out and its total was calculated.

The combination with least square sum of difference value was finally adopted. Practically running a program for 3^9 times is slight impossible, so after running the program for about 150 times the combination with least square sum of difference value was finally adopted.

The actual values adopted for the membership values s_z^1 , s_z^2, s_z^3, a_z^1, a_z^2, a_z^3 , d_z^1, d_z^2, d_z^3 in the proposed model are presented in the table below.

Table 5.1 Parameters of the membership functions of the premise variables

Parameter	Value	Figure referred
s_z^1	0.15	Fig 4.9
s_z^2	0.35	Fig 4.9
s_z^3	0.55	Fig 4.9
a_z^1	0.12	Fig 4.10
a_z^2	0.32	Fig 4.10
a_z^3	0.42	Fig 4.10
d_z^1	1.50	Fig 4.11
d_z^2	2.50	Fig 4.11
d_z^3	3.50	Fig 4.11

5.2.2 Rules adopted for Fuzzy Inference System

There are total 27 rules in the proposed model so each of the rules is listed below;

Rule 1

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is near

Then go with speed S_1.

Rule 2

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is far

Then go with speed S_2.

Rule 3

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is very far

Then go with speed S_3.

Rule 4

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is near

Then go with speed S_4.

Rule 5

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is far

Then go with speed S_5.

Rule 6

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is very far

Then go with speed S_6.

Rule 7

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is near

Then go with speed S_7.

Rule 8

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is far

Then go with speed S_8.

Rule 9

If number of vehicles in same strip is few AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is very far

Then go with speed S_9.

Rule 10

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is near

Then go with speed S_{10}.

Rule 11

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is far

Then go with speed S_{11}.

Rule 12

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is very far

Then go with speed S_{12}.

Rule 13

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is near

Then go with speed S_{13}.

Rule 14

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is far

Then go with speed S_{14}.

Rule 15

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is very far

Then go with speed S_{15}.

Rule 16

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is near

Then go with speed S_{16}.

Rule 17

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is far

Then go with speed S_{17}.

Rule 18

If number of vehicles in same strip is moderate AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is very far

Then go with speed S_{18}.

Rule 19

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is near

Then go with speed S_{19}.

Rule 20

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is far

Then go with speed S_{20}.

Rule 21

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is less AND

Distance of test vehicle from road edge is very far

Then go with speed S_{21}.

Rule 22

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is near

Then go with speed S_{22}.

Rule 23

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is far

Then go with speed S_{23}.

Rule 24

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is moderate AND

Distance of test vehicle from road edge is very far

Then go with speed S_{24}.

Rule 25

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is near

Then go with speed S_{25}.

Rule 26

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is far

Then go with speed S_{26}.

Rule 27

If number of vehicles in same strip is large AND

Number of vehicles in adjacent strip is high AND

Distance of test vehicle from road edge is very far

Then go with speed S_{27}.

The exact values of S values i.e. S_1, S_2……S_{27} are given in section 5.2.3.

5.2.3 Calibration of consequence variables (S values)

S value indicates the speed value or value of the consequence variable. As per section 3.4.2 of Bicycle Infrastructure Design Manual for Indian Sub-continent maximum speed of a cycle in main cycle rout is 30 kmph and in other routs with mixed traffic is 20 kmph. In this project unit taken is in meters per second so maximum speed should be 5.5 m per sec. but on a safe side the maximum speed is taken as 8 m per sec and minimum speed as 1 m per sec. the table below give the exact vales adopted for S_1, S_2….S_{27}.

Table 5.2 exact S value used in the model.

Parameter	Value in m/sec
S_1	5.00
S_2	6.20
S_3	8.00
S_4	3.40
S_5	4.20
S_6	5.80
S_7	3.00
S_8	3.30
S_9	4.90
S_{10}	3.50
S_{11}	4.00
S_{12}	6.00
S_{13}	2.60
S_{14}	3.60
S_{15}	4.25
S_{16}	2.40
S_{17}	3.30
S_{18}	3.75
S_{19}	2.70
S_{20}	4.10
S_{21}	5.20
S_{22}	2.50
S_{23}	3.40
S_{24}	4.40
S_{25}	1.50
S_{26}	2.20
S_{27}	3.00

5.3 Model validation

After calibration of the model i.e. after fixing all membership values of premise variable, defining all 27 rule and after fixing the values of consequence variable; it's time to check the model. Hence the model was validated by entering the data obtained from road near aambagan market, Rourkela as input parameter, rest of the value mentioned above were not changed. It was seen that the results in form of speed data are almost same as that obtained by experimentally.

5.4 simulation results

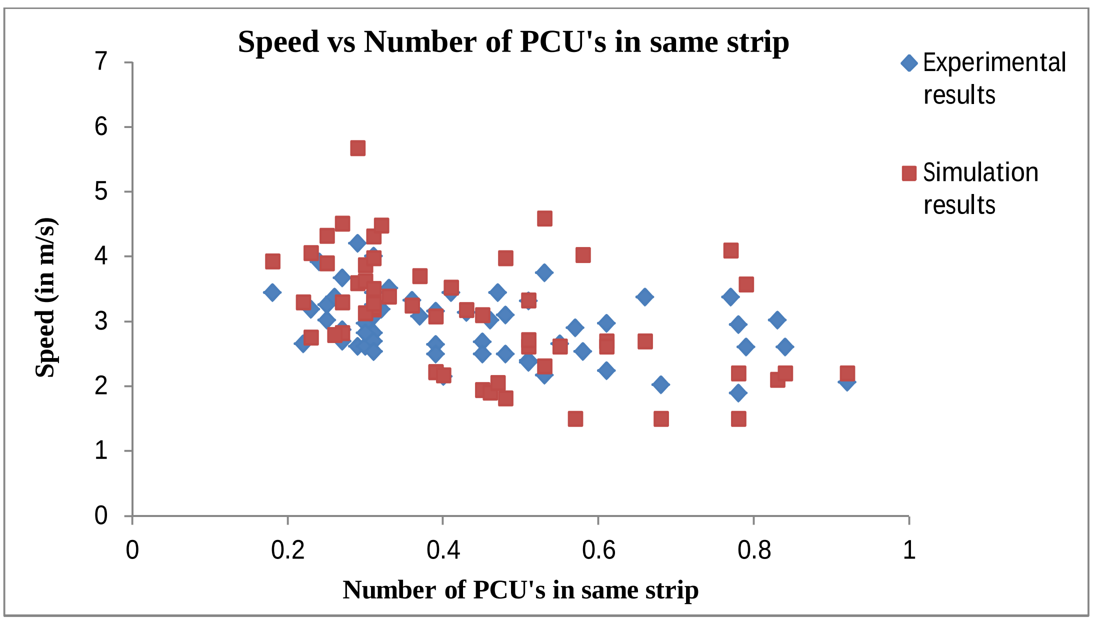


Fig 5.2 Speed versus number of PCU's in same strip for road near main market

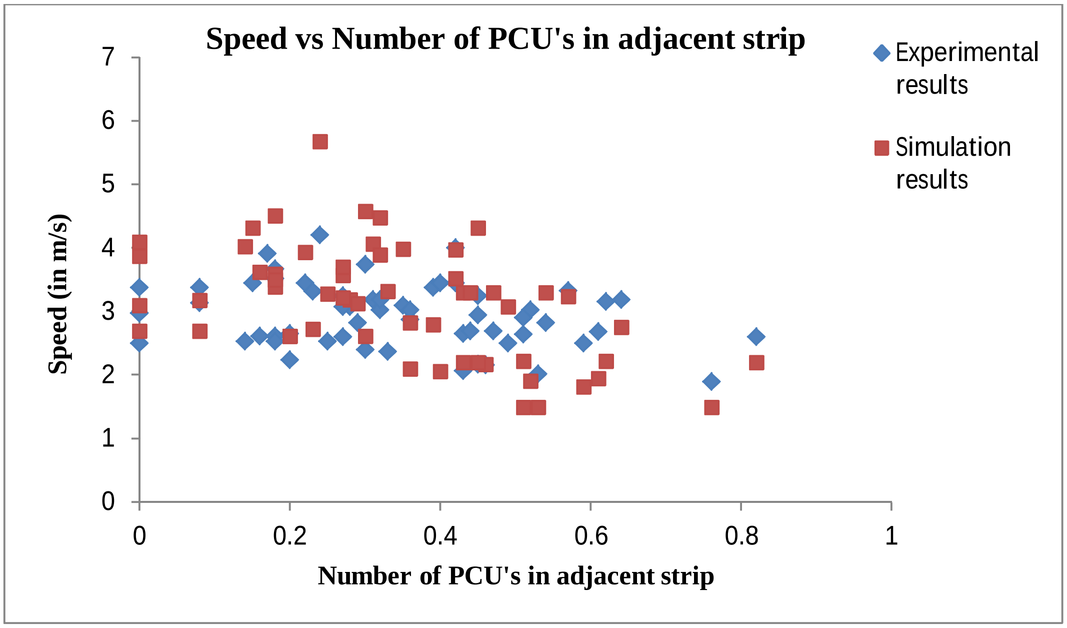


Fig 5.3 Speed versus number of PCU’s in alternate strip for road near main market

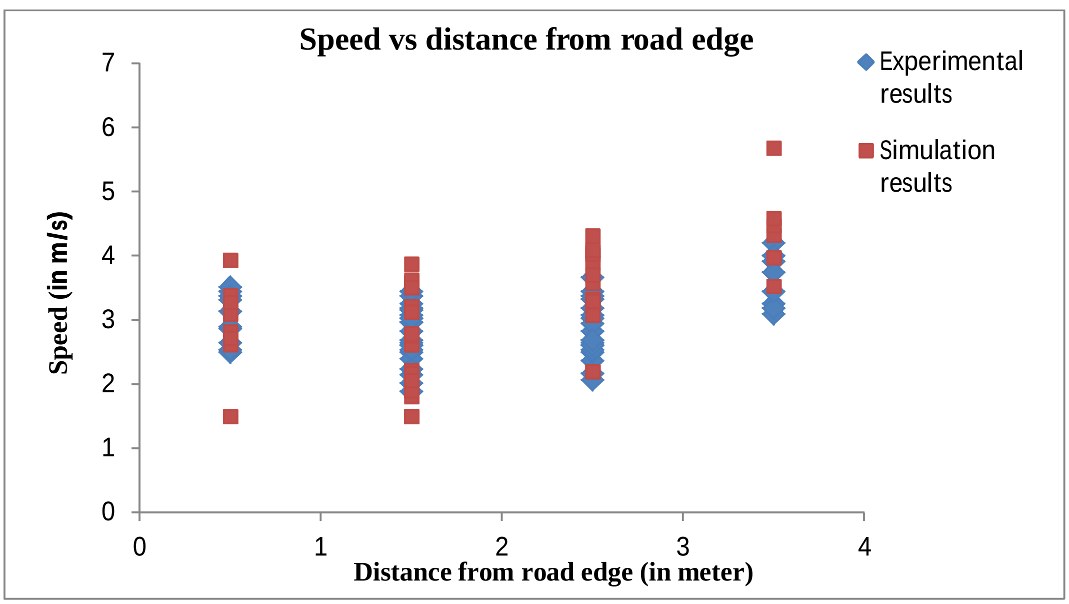


Fig 5.4 Speed versus distance from road edge for road near main market

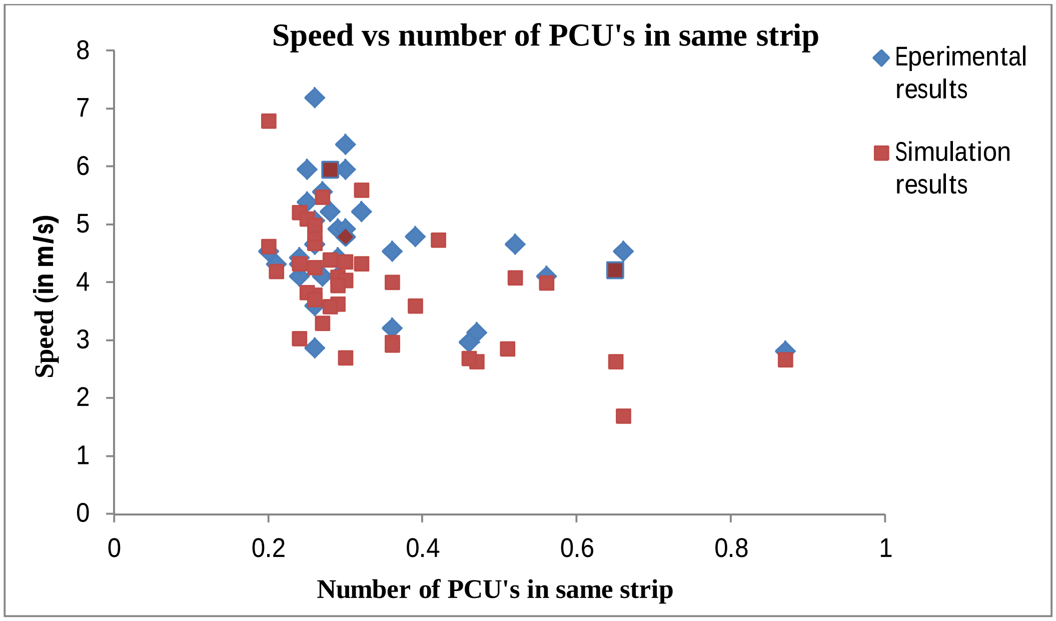


Fig 5.5 Speed versus number of PCU’s in same strip for road near Aambagan

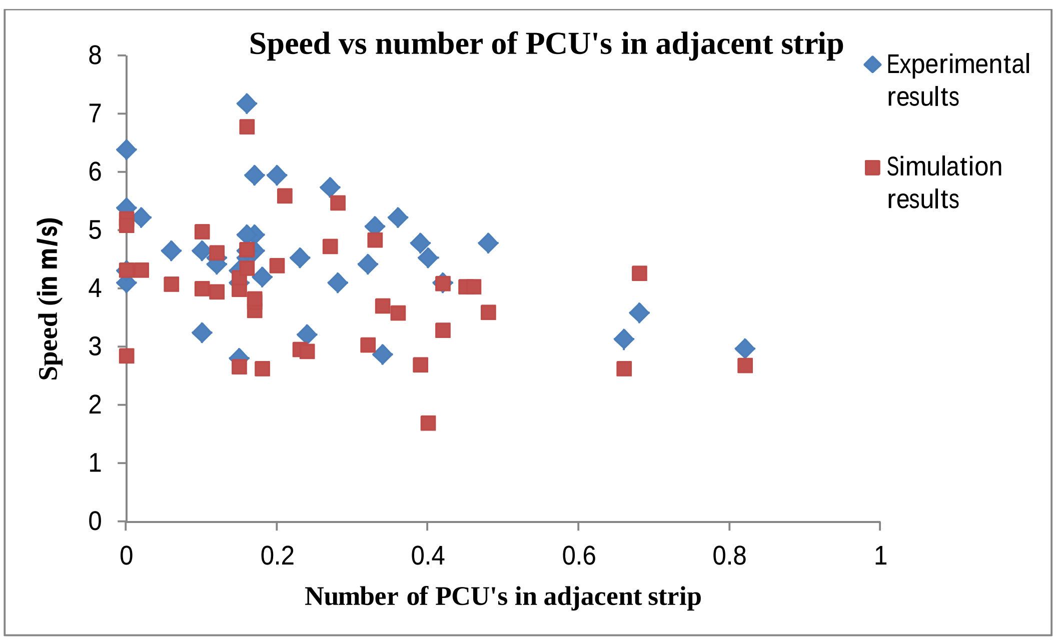


Fig 5.6 Speed versus number of PCU’s in adjacent strip for road near Aambagan

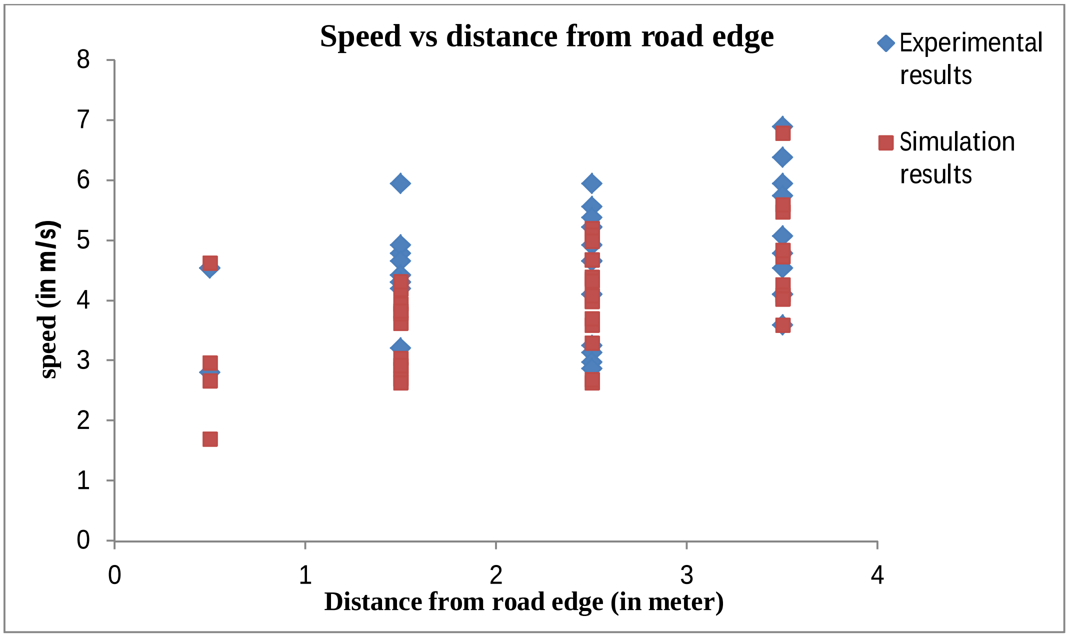


Fig 5.7 Speed versus distance from road edge for road near Aambagan

From fig 5.1 to 5.7 it has been seen that as far as the simulation results are concerned it was seen that speed value obtained experimentally and obtained from the model are almost same. So the model can be used for roads with mixed traffic with single lane of flow.

Chapter 6

6. Conclusion

In fundamental diagram the plot is similar to it is being expected. The graph shows partial density of the region, because within 30 min video getting the free and congested flow at a time is practically not possible. Anyhow in one location some point of congested flow is also achieved. While comparing the flow versus density curve for various location with respect to various percentage of NMV it was found that that with increase in NMV percentage an adverse effect was noticed on the flow of the mixed traffic. Density decreases at a particular flow rate when NMV percentage increases.

In lateral occupancy graph it can be seen that the NMVs trying to stay in left hand side of the road. As in India we follow left hand side drive the MVs try to overtake them and are found mostly in the right hand side of the road. Also the first strip or 1 m from the left edge remains almost empty because vehicles normally try to avoid moving at the edge when there are either no shoulders or raised curves are there. Roads in which there are shoulders the vehicles are found in the first strip from left hand side as well.

Density data obtained from all the location are almost same, so it is not possible to predict the trend of lateral occupancy.

But with respect to percentage of NMV the predictions are like with less NMV percentage the non-motorised vehicles although found mostly in the left side i.e. strip 1 and 2 but are unevenly distributed. With moderate NMV percentage the non-motorized vehicle follow a trend and are segregated not only in the left but also found maximum in the middle part of the road occupying strip 2 and 3. With high NMV percentage the non-motorised vehicles are evenly distributed in the entire space and trying to occupy the right hand side of the road blocking the way for flow from other direction.

With less NMV percentage the motorised vehicles don't face any problem and are evenly distributed in the entire flow space in that direction. With moderate NMV percentage motorised vehicles are trying to overtake the NMVs but as there is a flow from other direction as well so they are mostly occupying the middle part of their flow space i.e. strip 3 and 4. When NMV percentage is high then motorised vehicle try to overtake them and are found in right hand side of the road i.e. strip 4, 5 and 6 occupying the space for the flow from other direction as well.

From the speed versus various parameters graph it can be concluded that speed of the non-motorised vehicles

1. Decreases when number of PCUs in same strip increases.
2. Decreases when number of PCUs in adjacent strip increases.
3. Increases when distance from the road edge increases.

As far as the simulation results are concerned it was seen that speed value obtained experimentally and obtained from the model are almost same. So the model can be used for roads with mixed traffic with single lane of flow.

In this model direction of the flow was not considered i.e. vehicles other than the test vehicle may be from the opposite direction of flow. So in future study the speed value can be modelled even more precisely if the direction of flow is taken into account separately.

Chapter7

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